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(54) **SEMICONDUCTOR MANUFACTURING APPARATUS INCLUDING A BEAM SHAPER FOR SHAPING A LASER BEAM**

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H01L 21/268 (2006.01)
B23K 26/066 (2014.01)
B23K 26/352 (2014.01)

(52) **U.S. Cl.**

CPC ***H01L 21/268*** (2013.01); ***B23K 26/066*** (2015.10); ***B23K 26/352*** (2015.10)

(58) **Field of Classification Search**

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USPC 438/487
See application file for complete search history.

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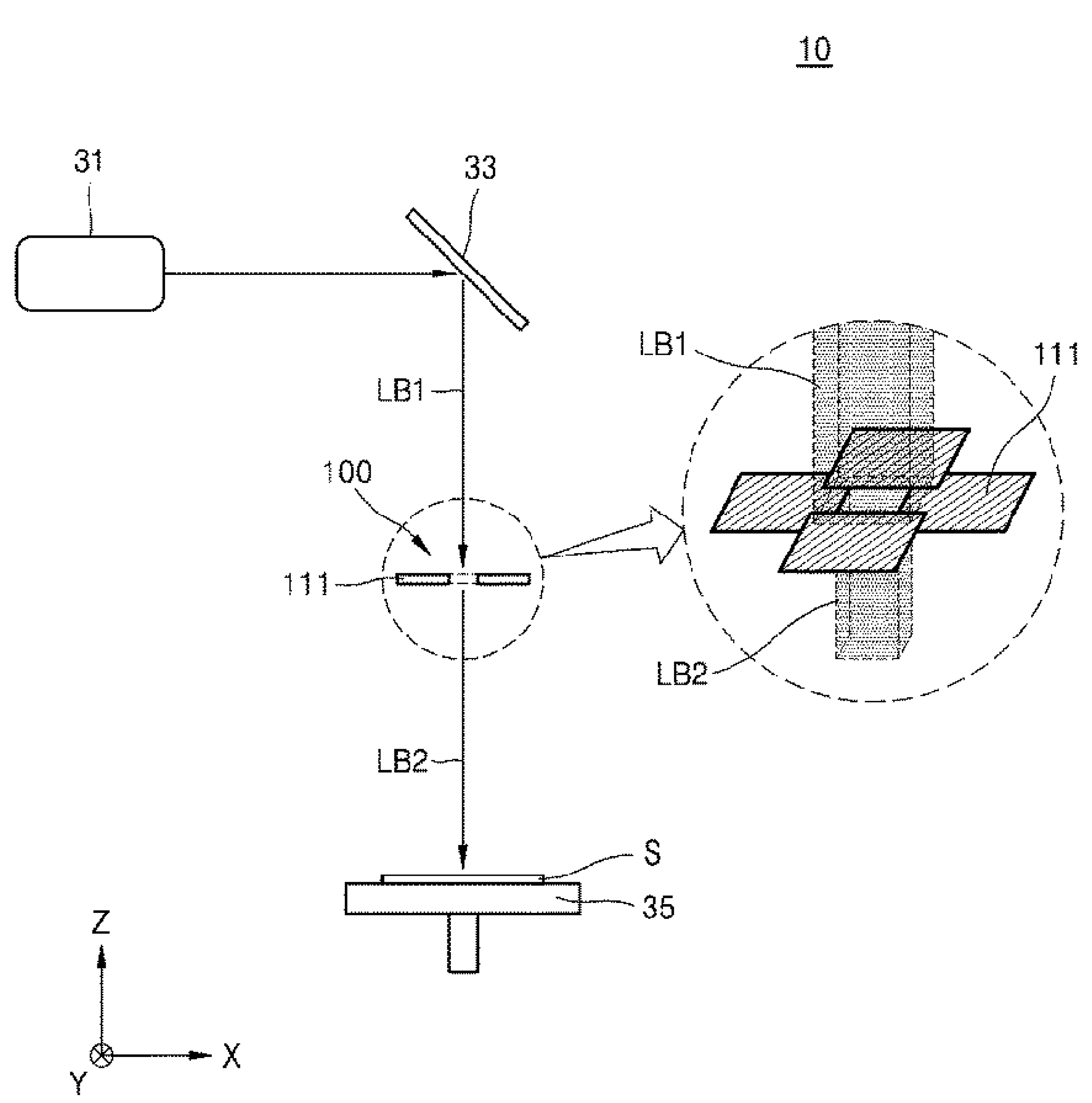
(57) **ABSTRACT**

A semiconductor manufacturing apparatus is provided including a beam shaper arranged on a light path of a laser beam and including a plurality of mask modules. The plurality of mask modules defines a light blocking region and a light transmitting region. At least one mask module of the plurality of mask modules includes a blocking plate configured to block a portion of the laser beam, and a driver is configured to move the blocking plate.

18 Claims, 17 Drawing Sheets



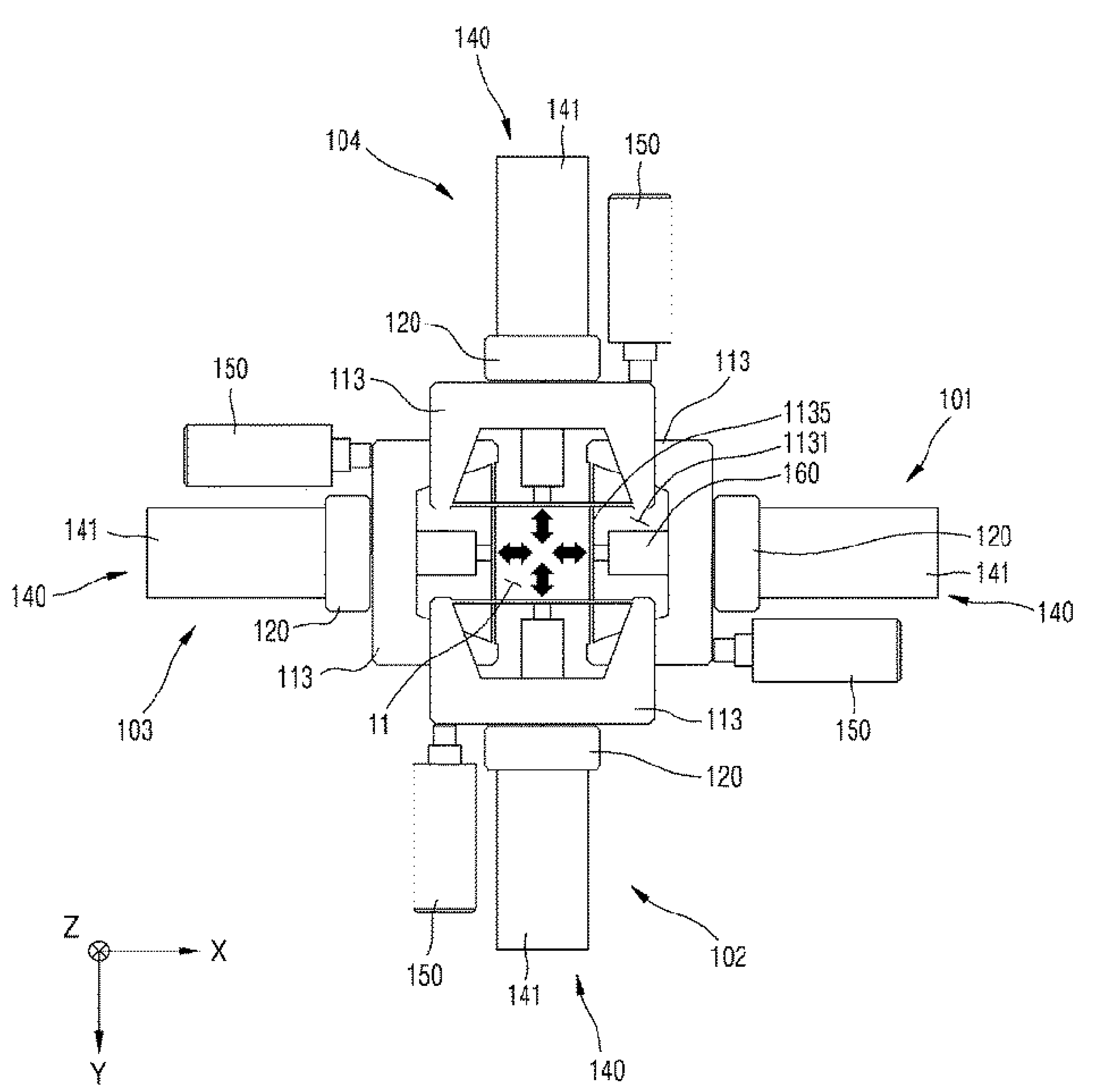


FIG. 1

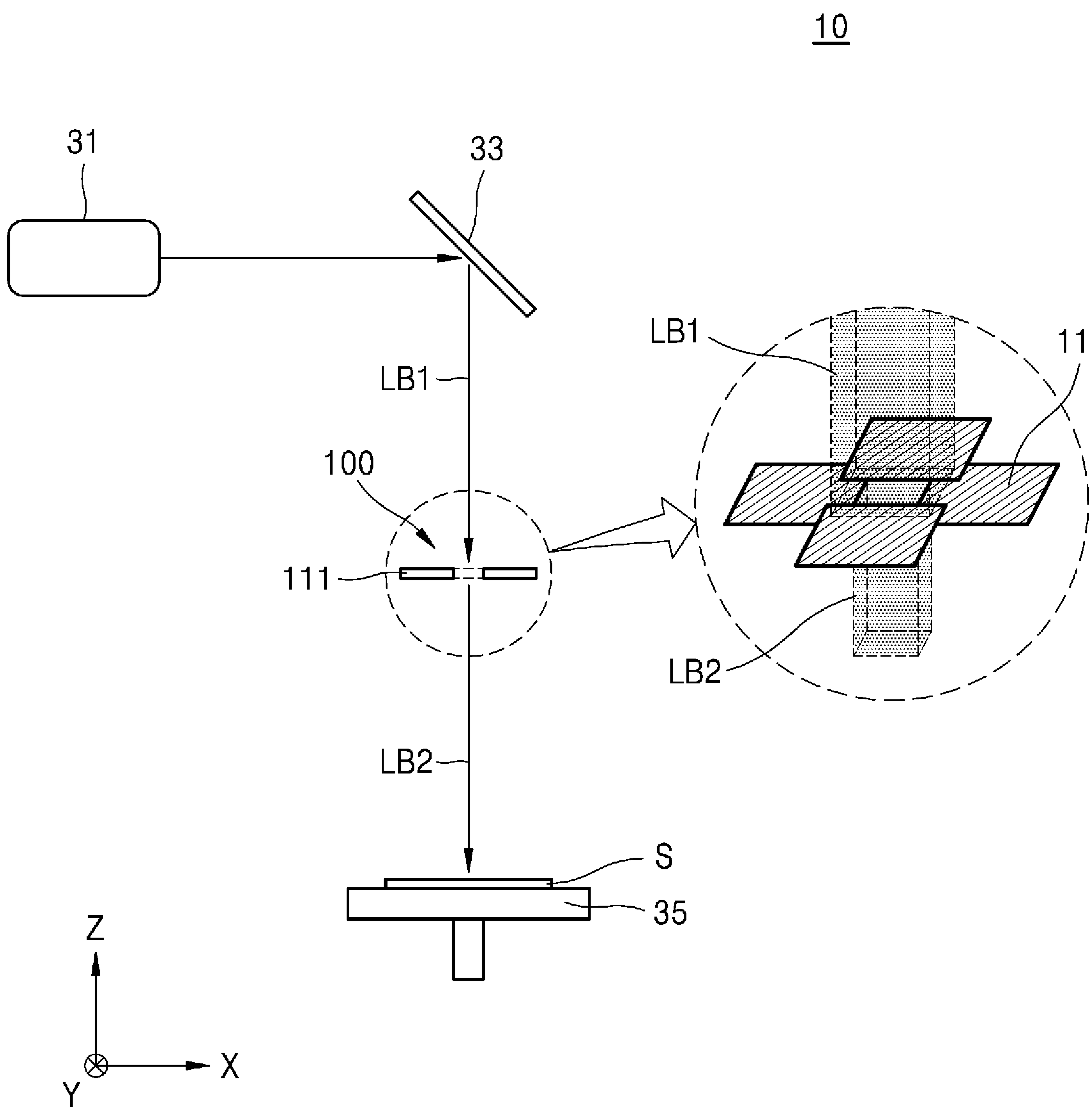


FIG. 2

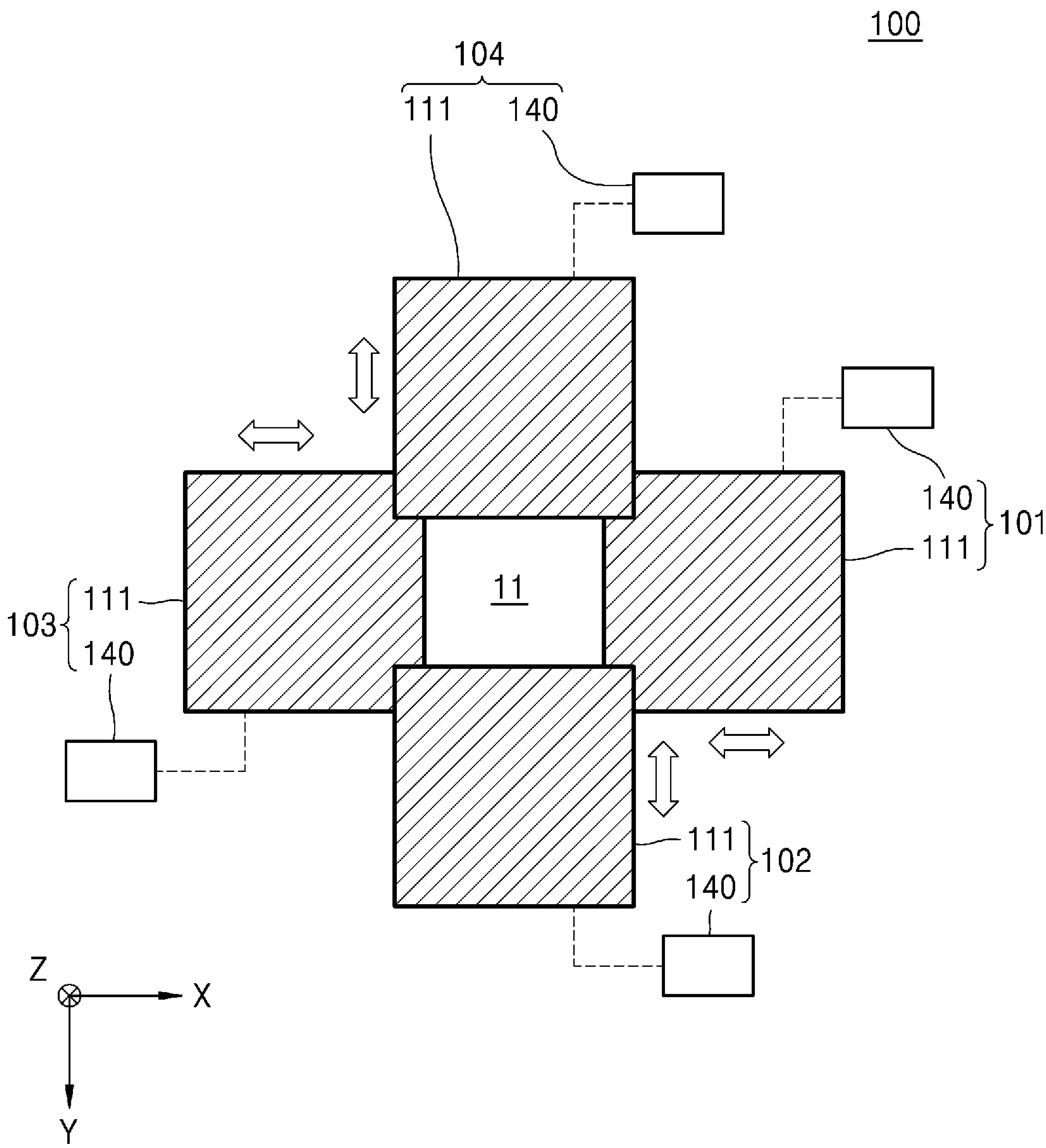


FIG. 3

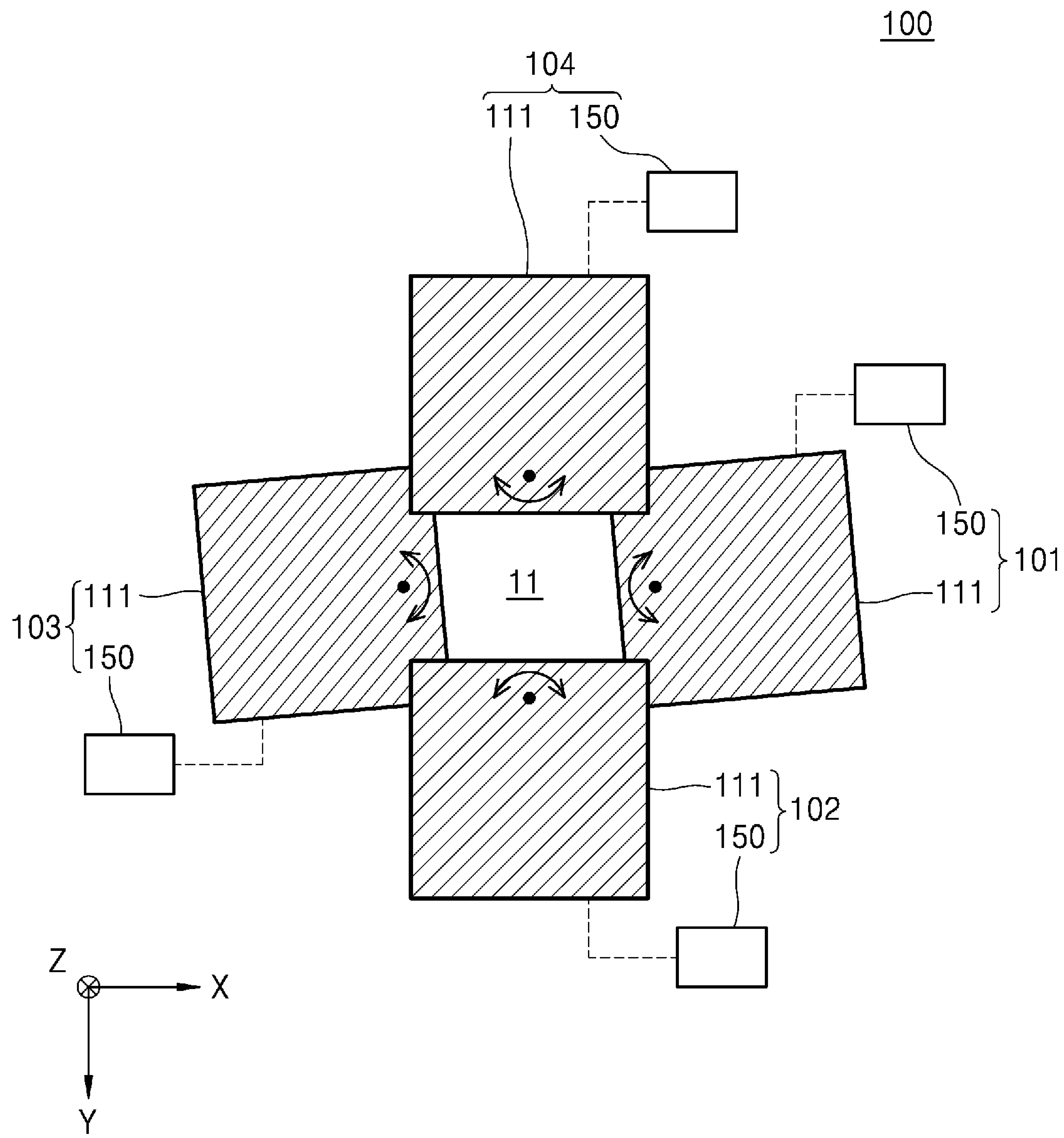


FIG. 4A

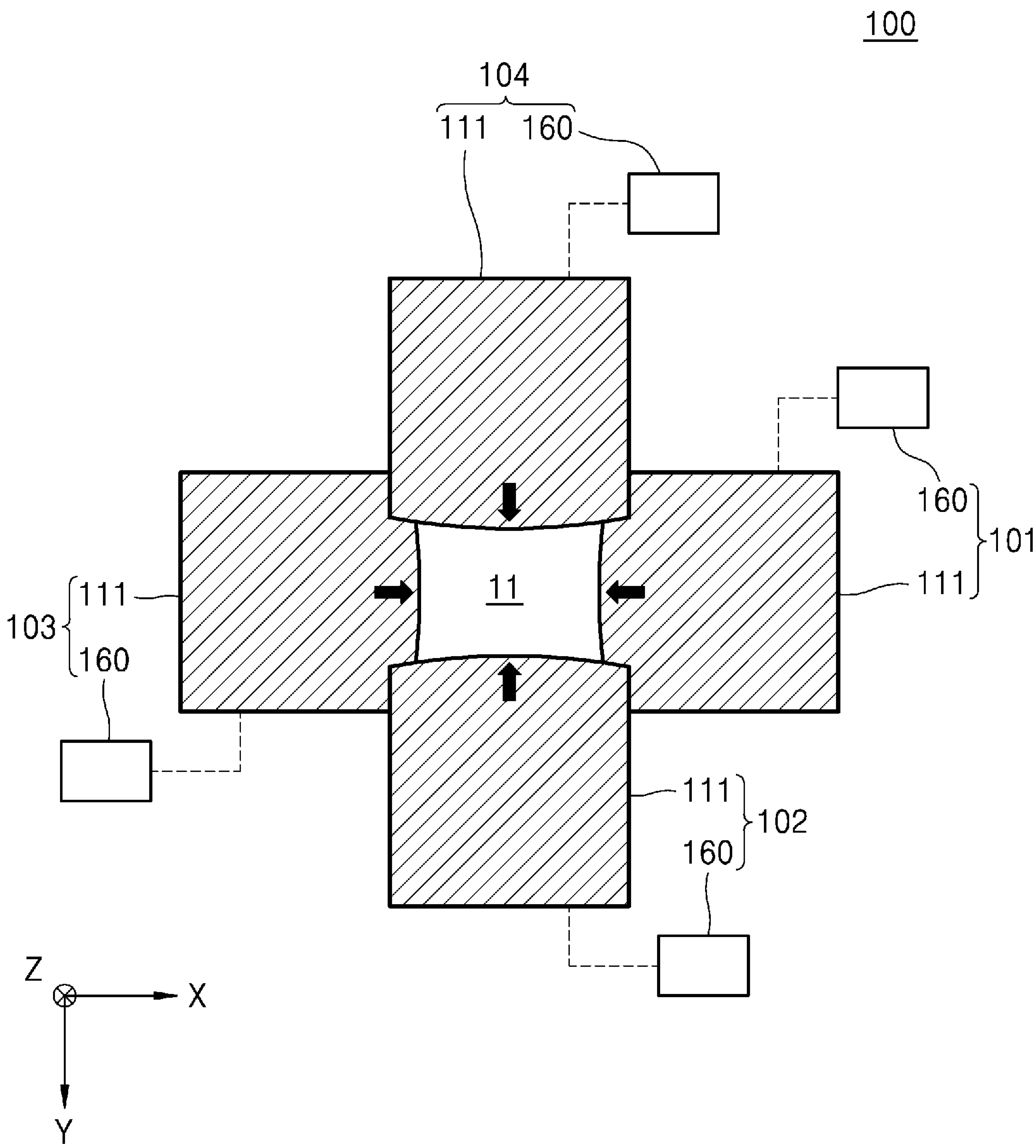


FIG. 4B

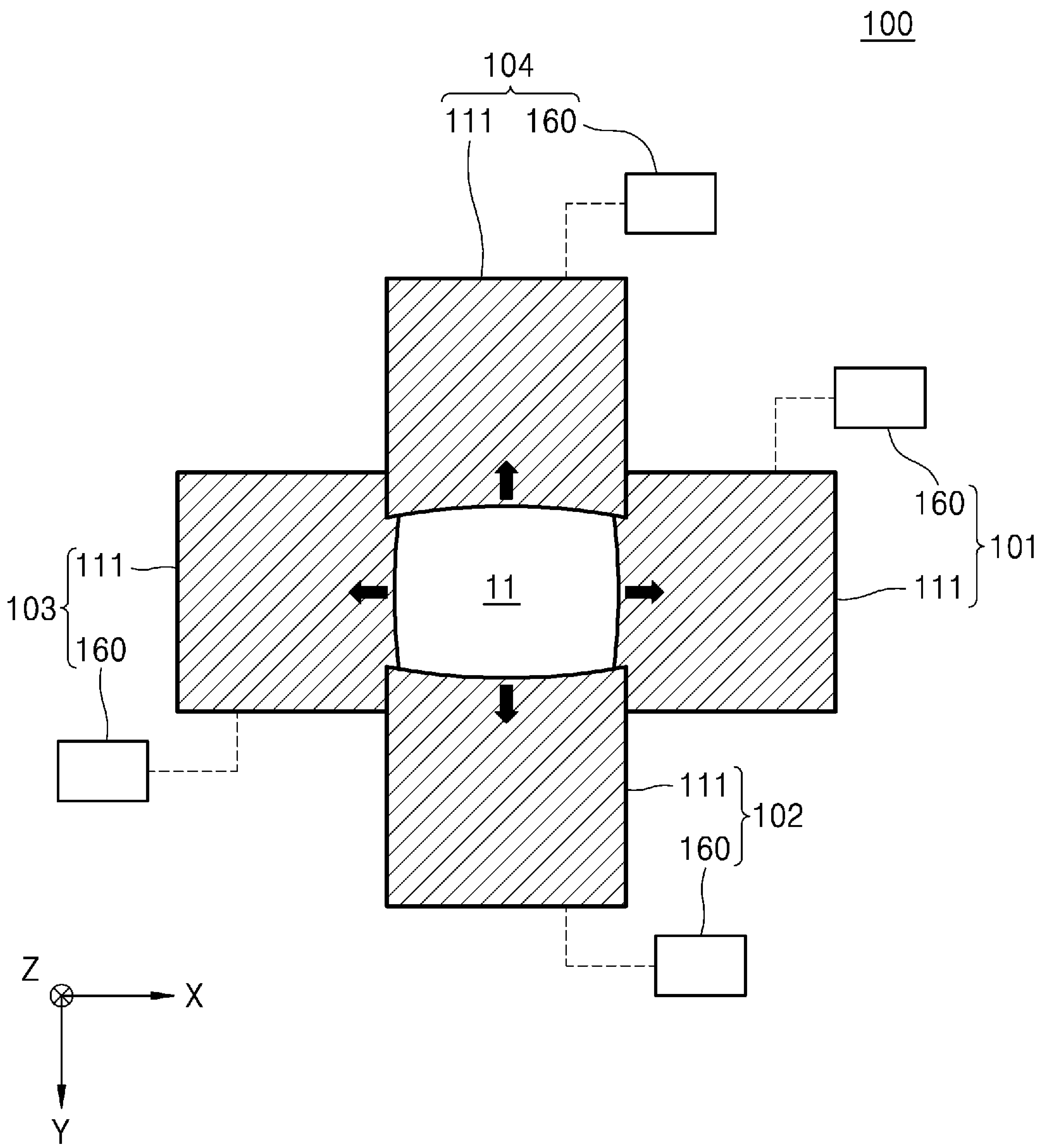
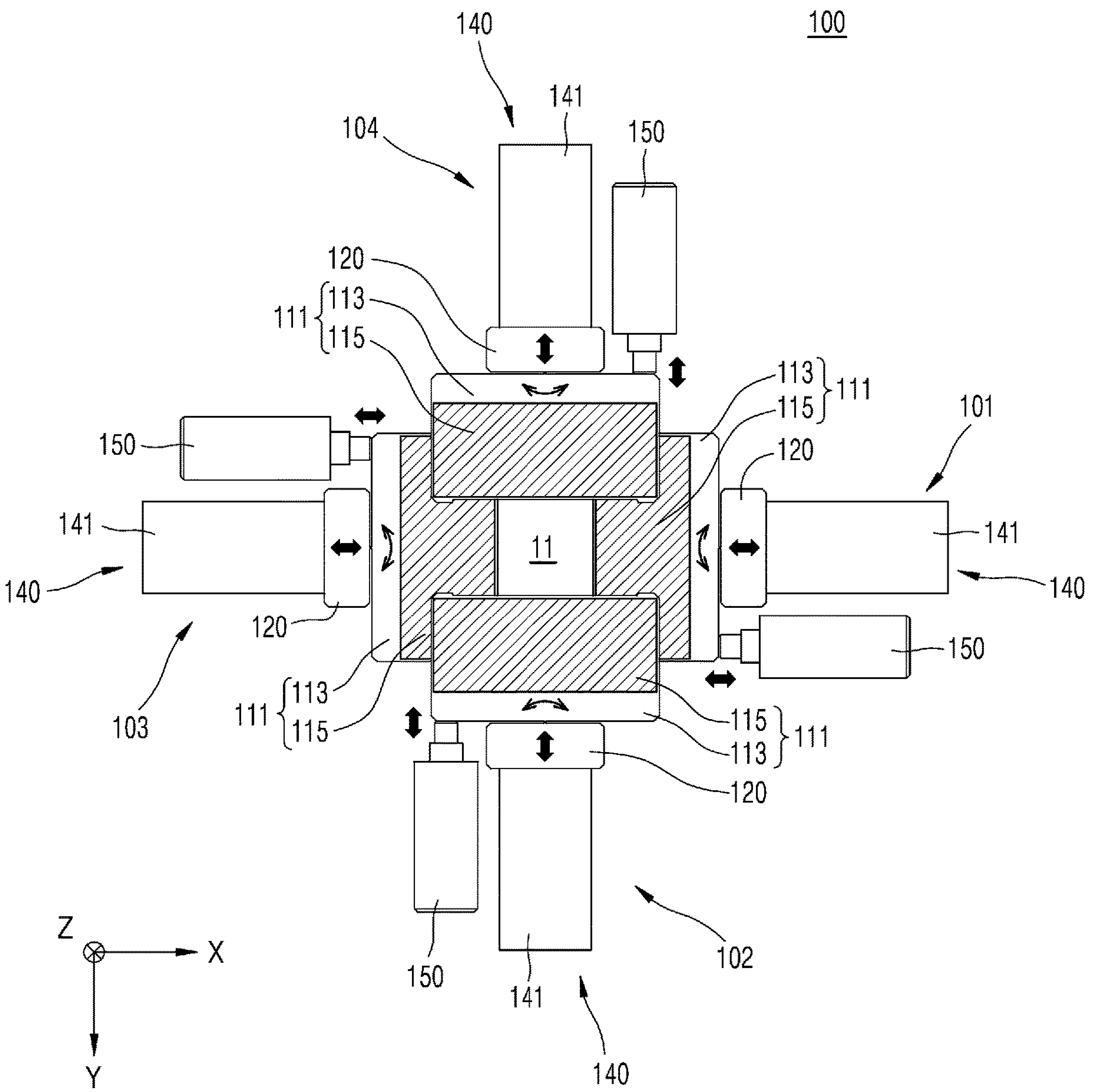


FIG. 5A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102
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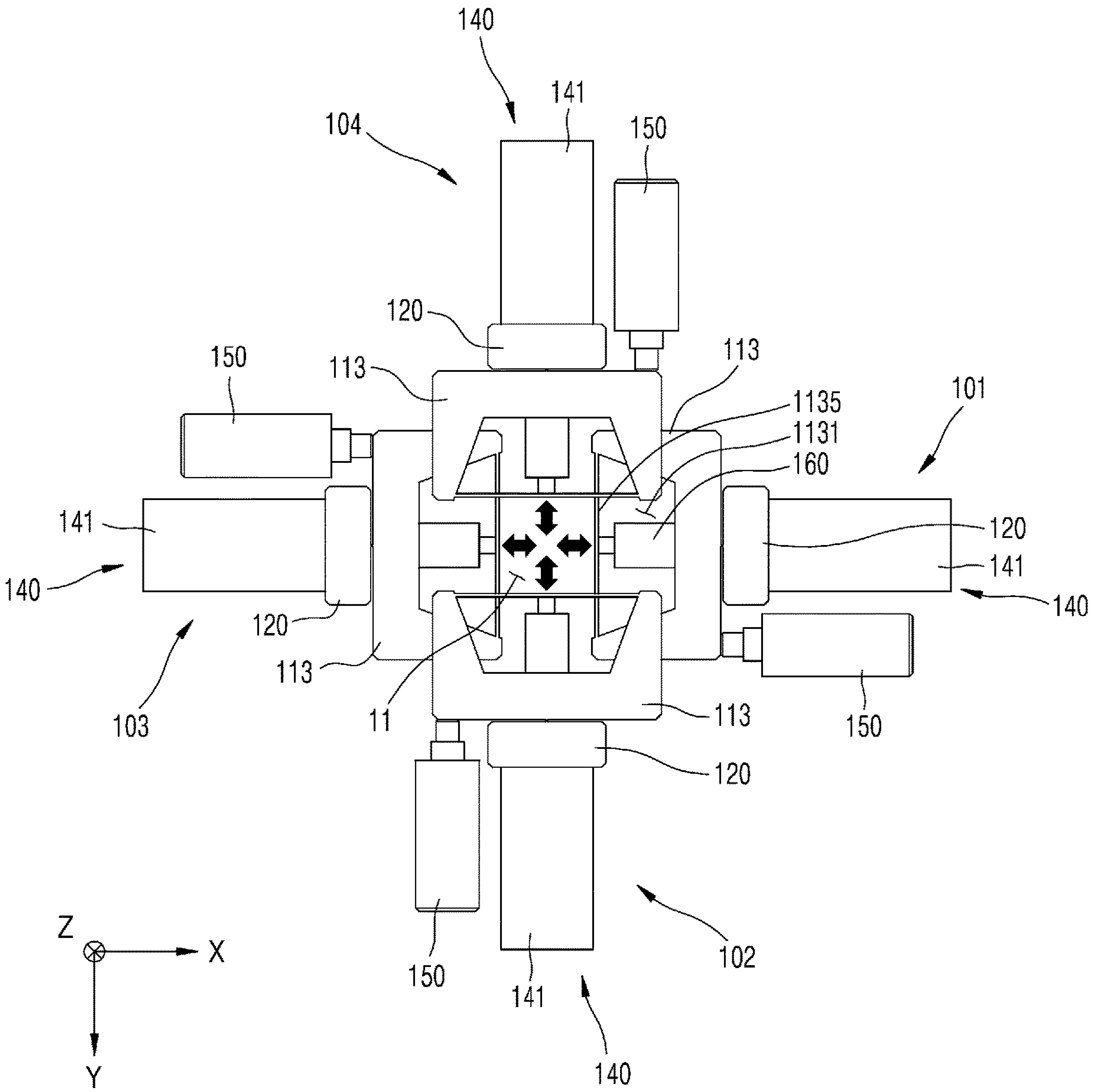
FIG. 5B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160
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FIG. 6A

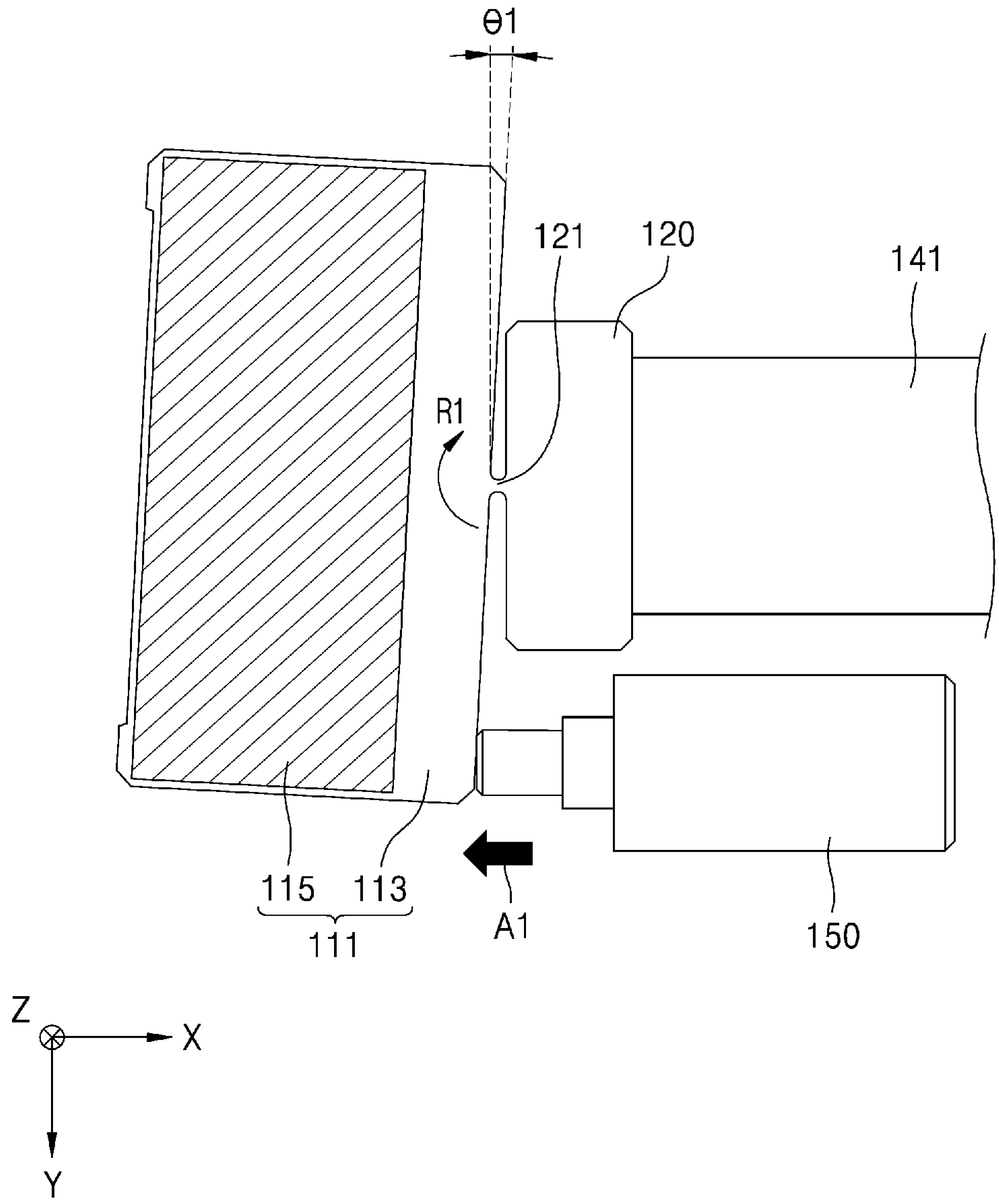

FIG. 6B

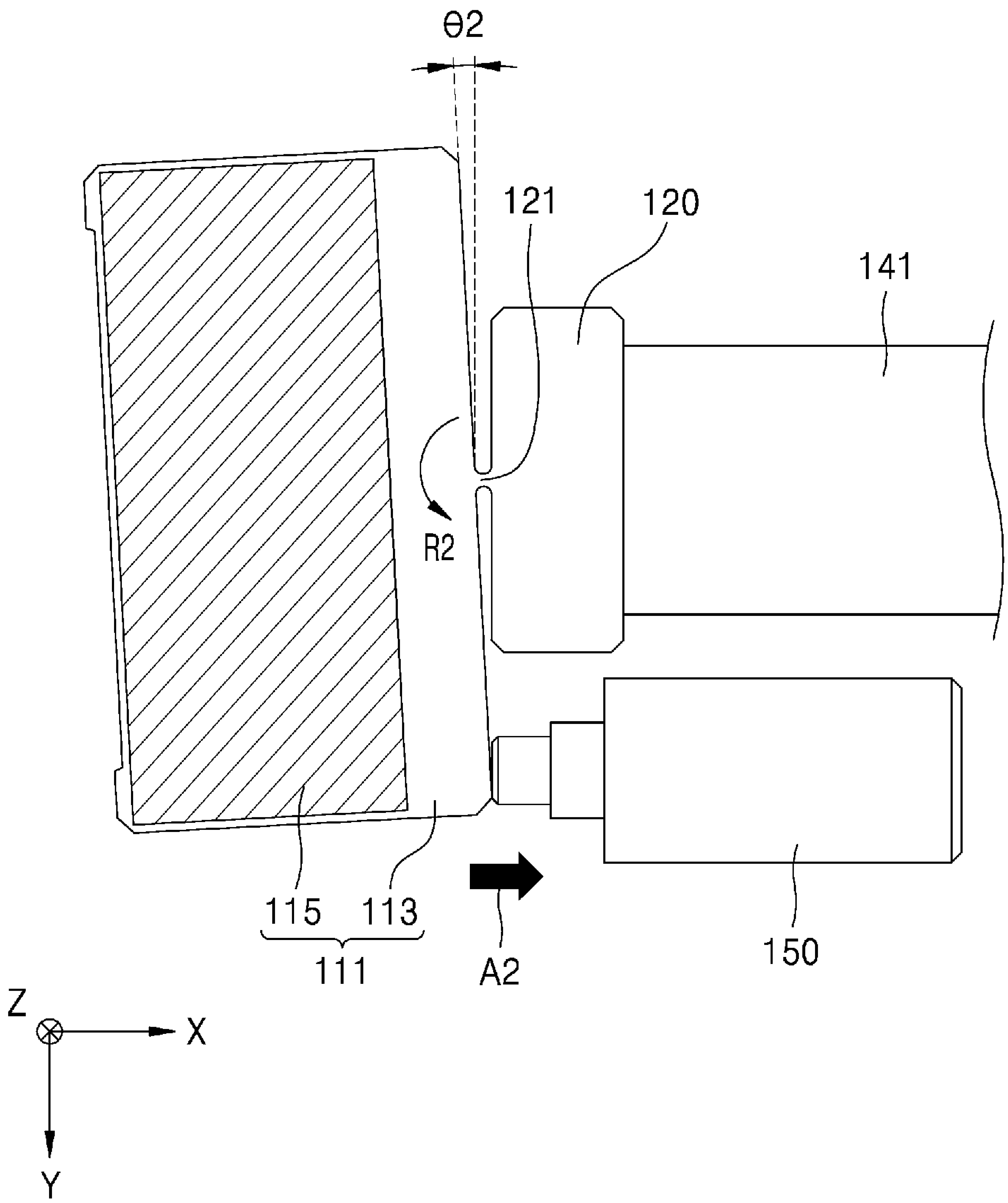

FIG. 7

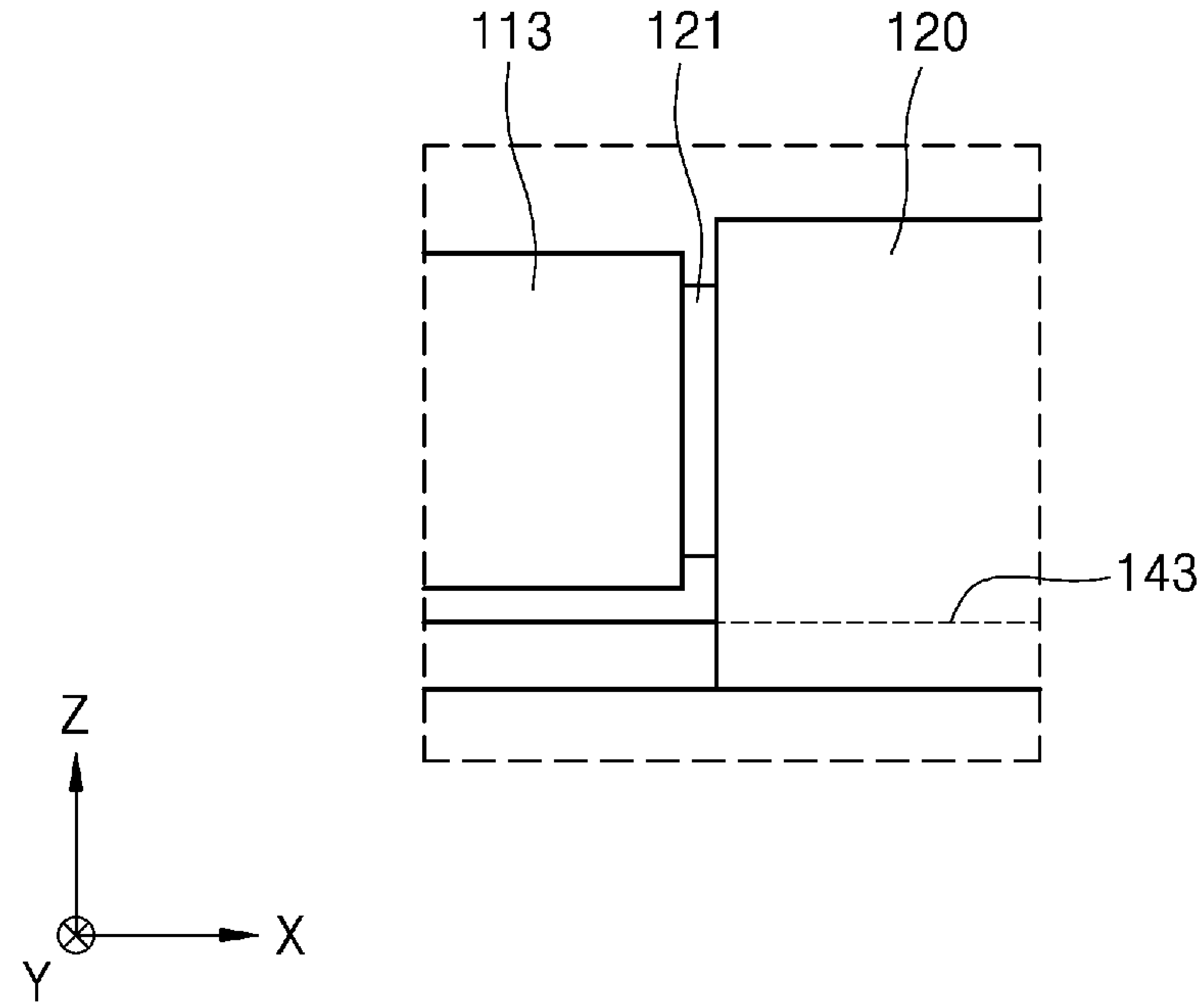

FIG. 8A

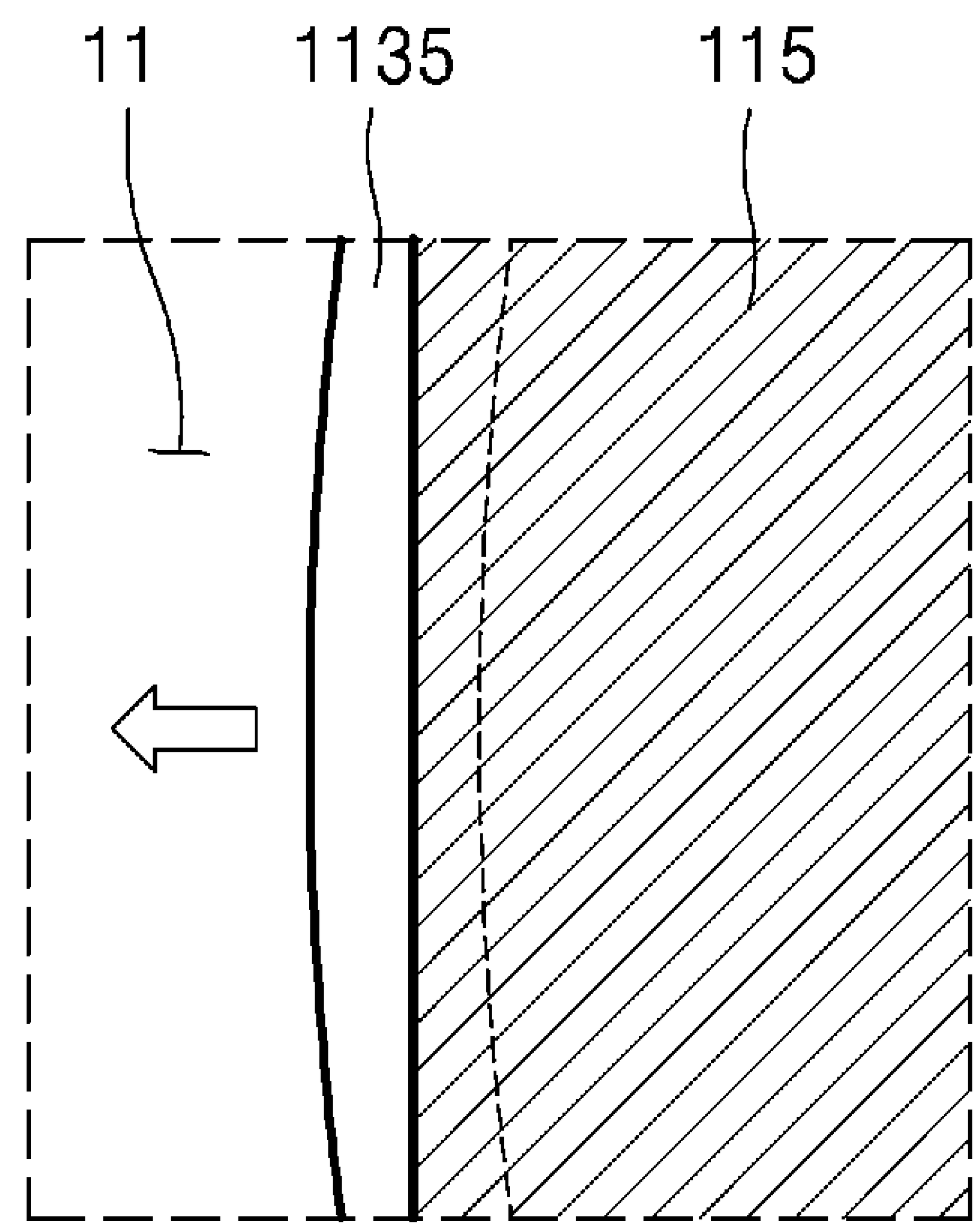

FIG. 8B

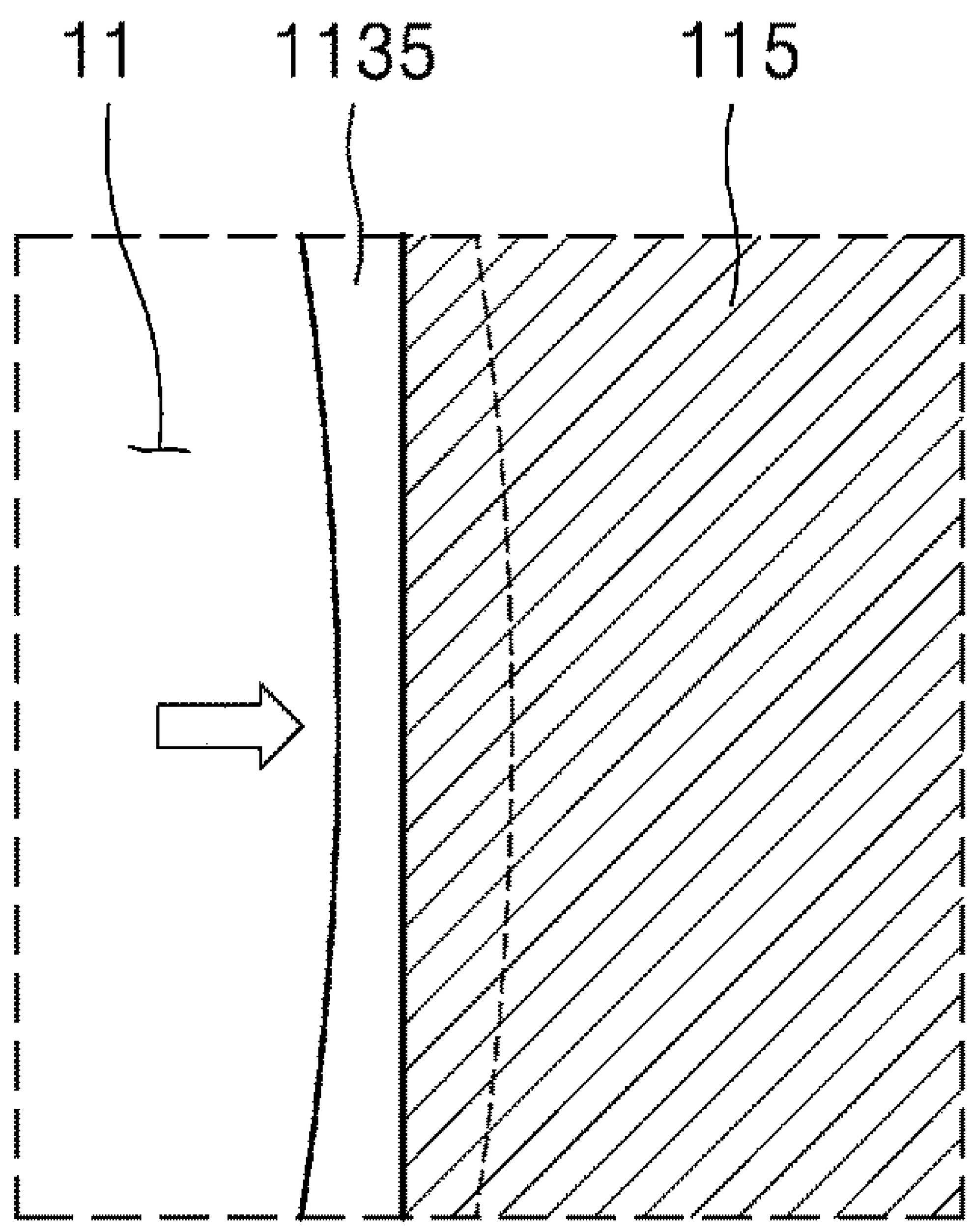

FIG. 9

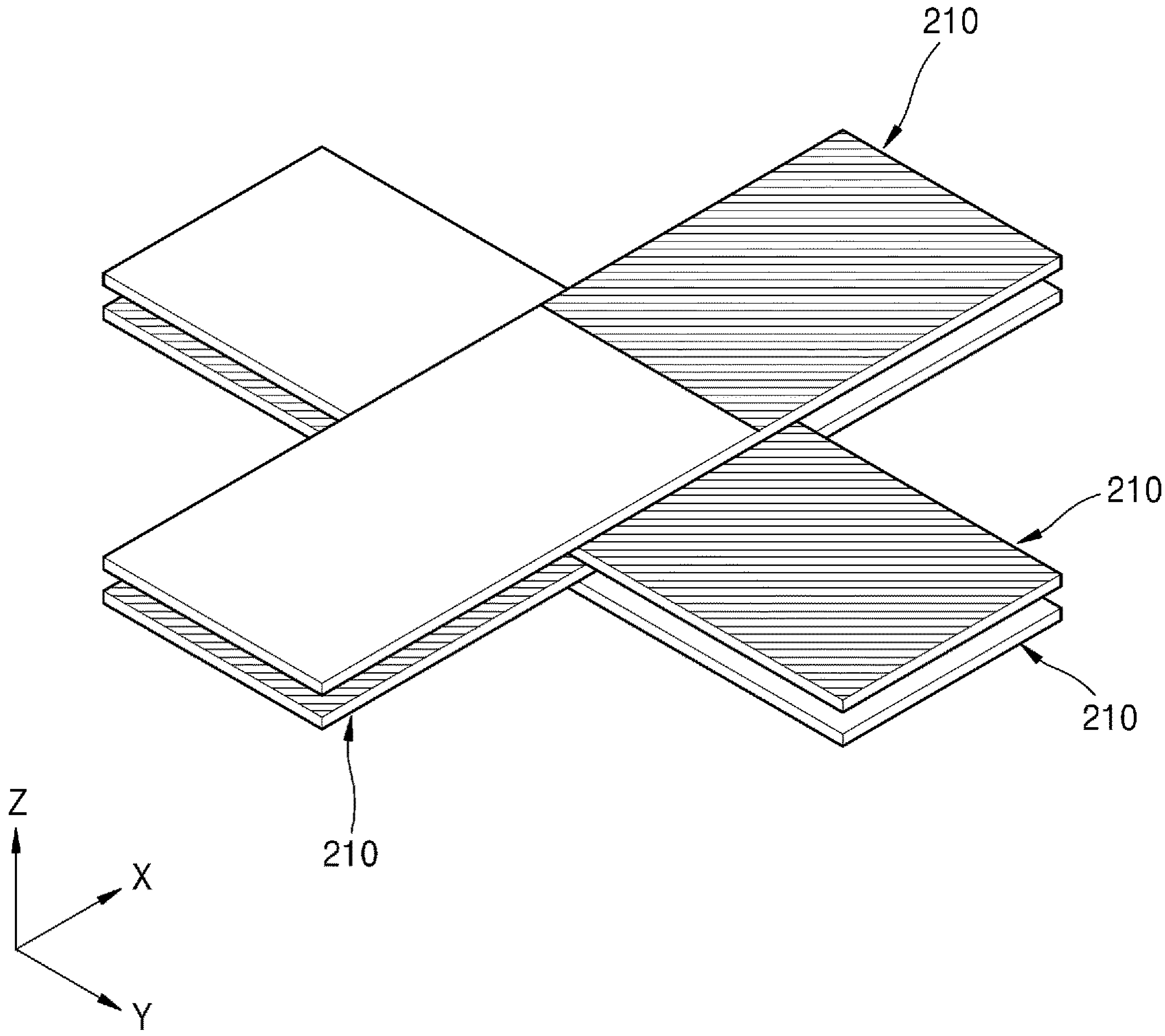

FIG. 10

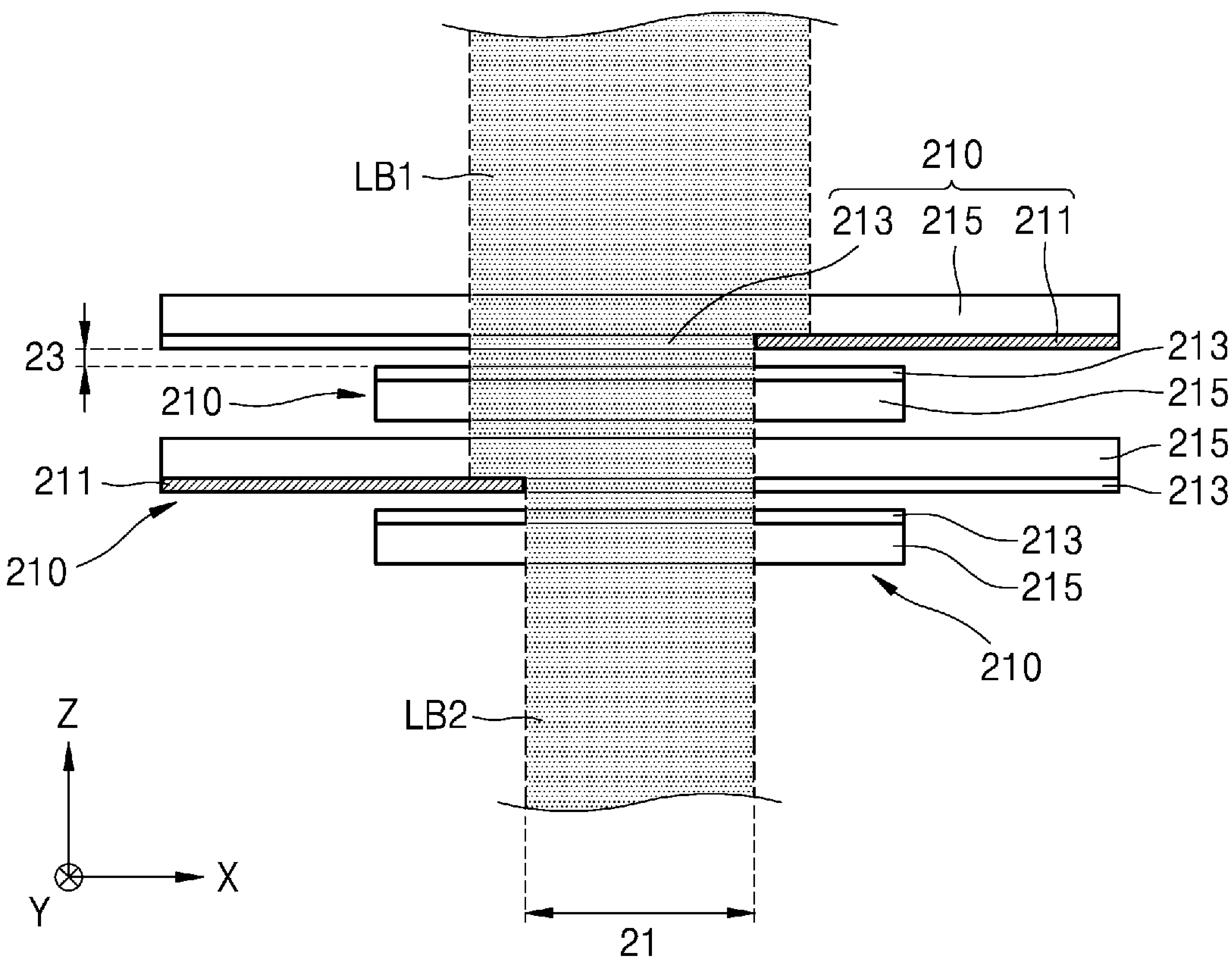
LB1
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FIG. 11

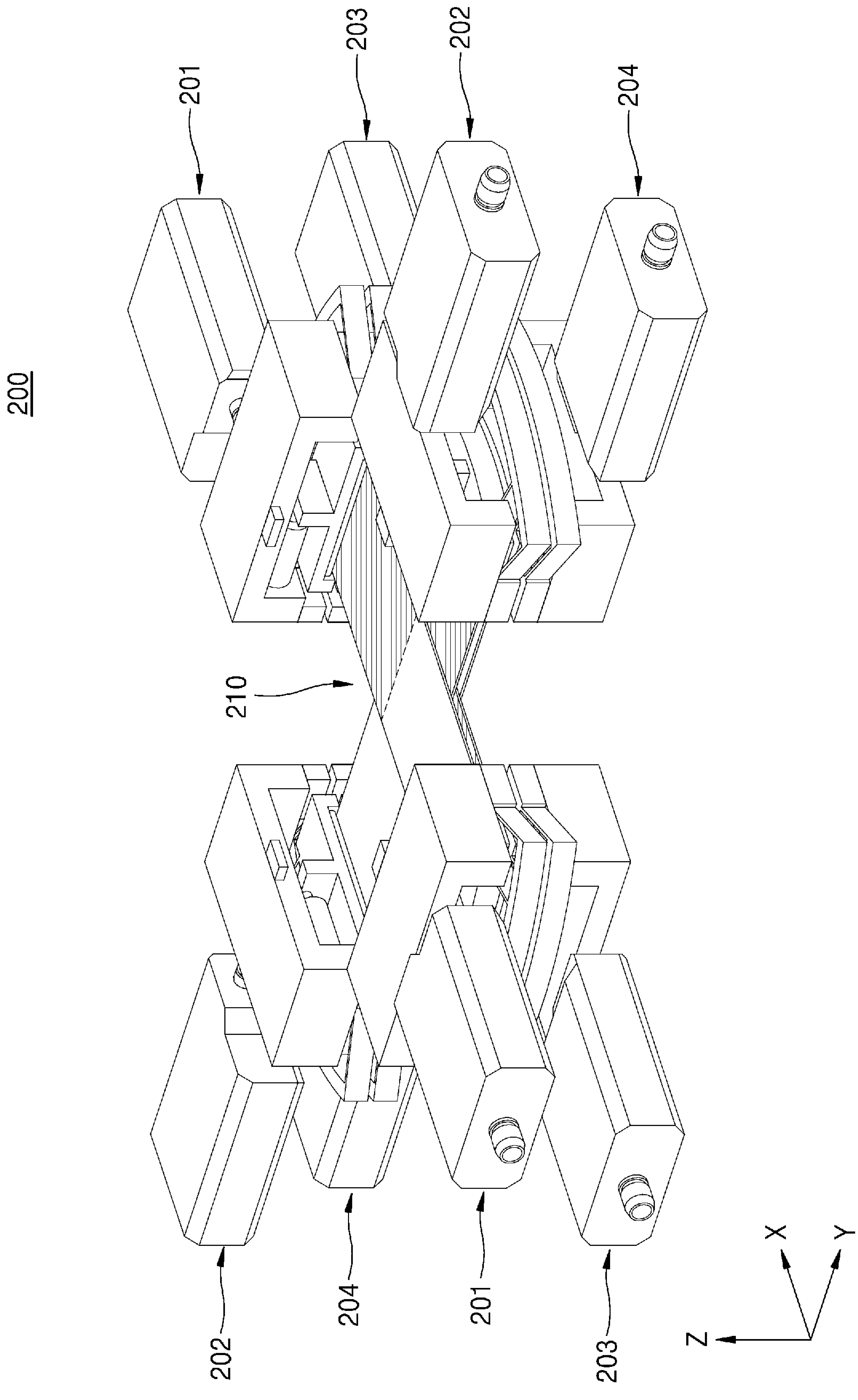

FIG. 12

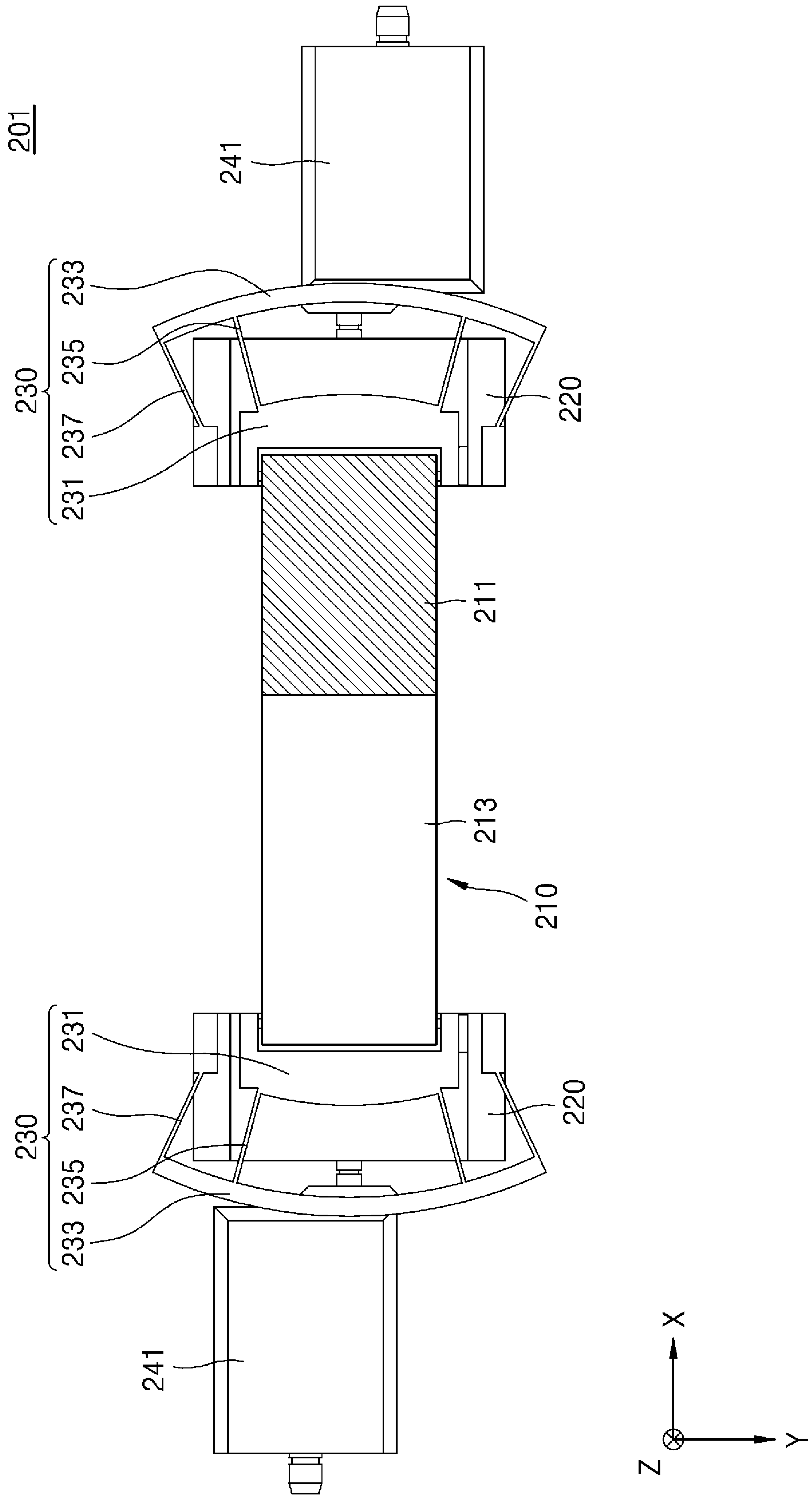

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FIG. 13

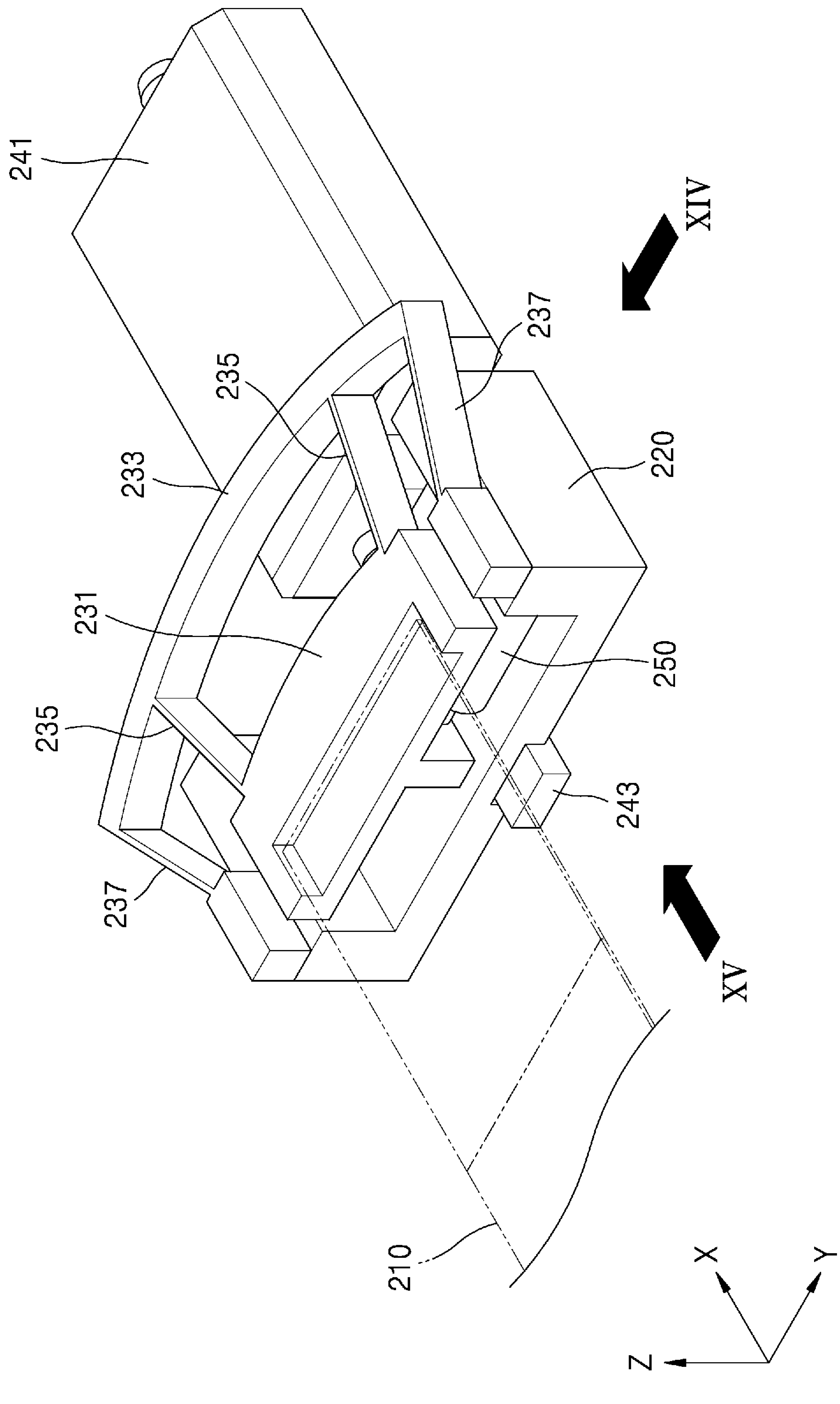


FIG. 14

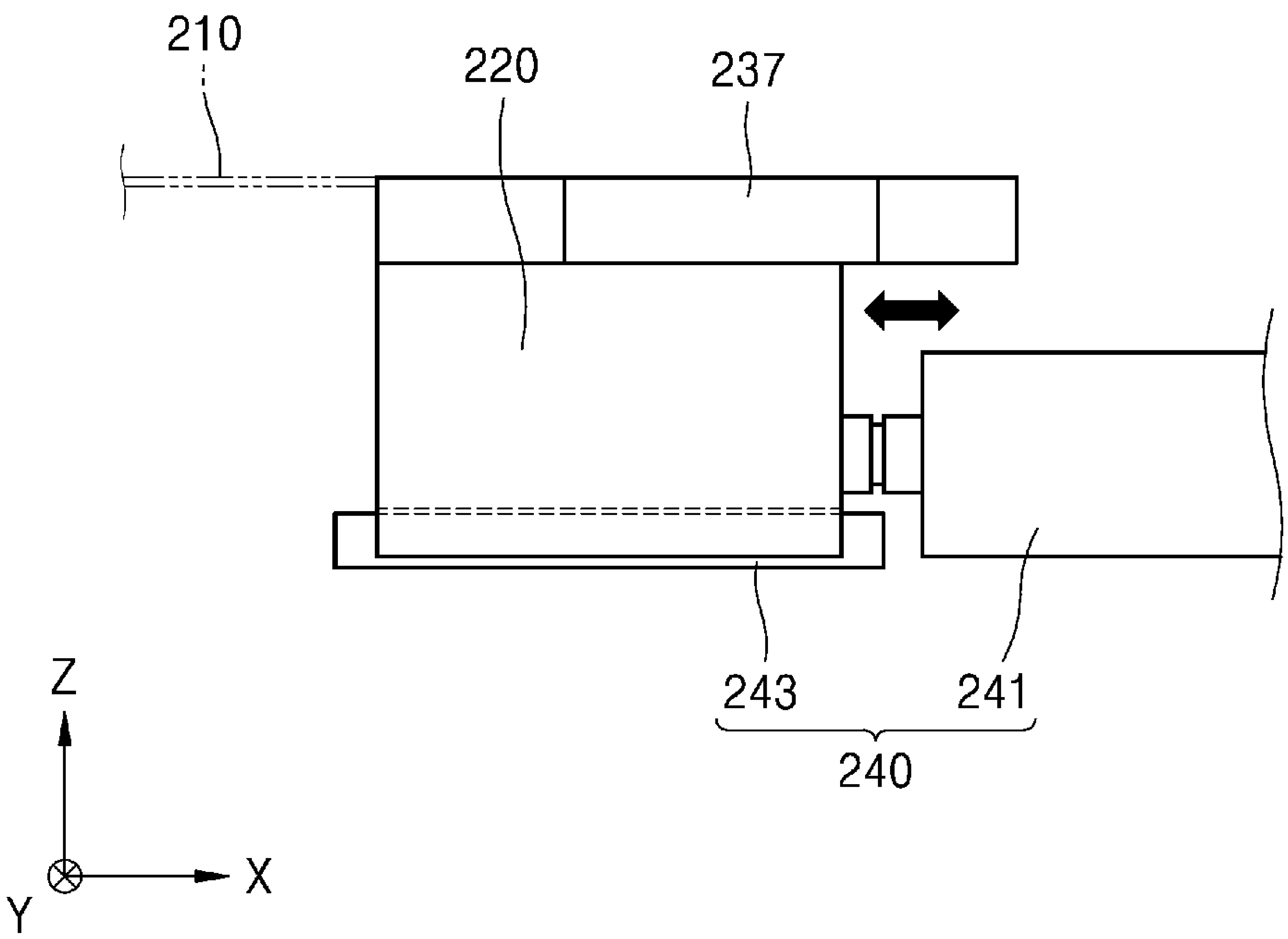


FIG. 15

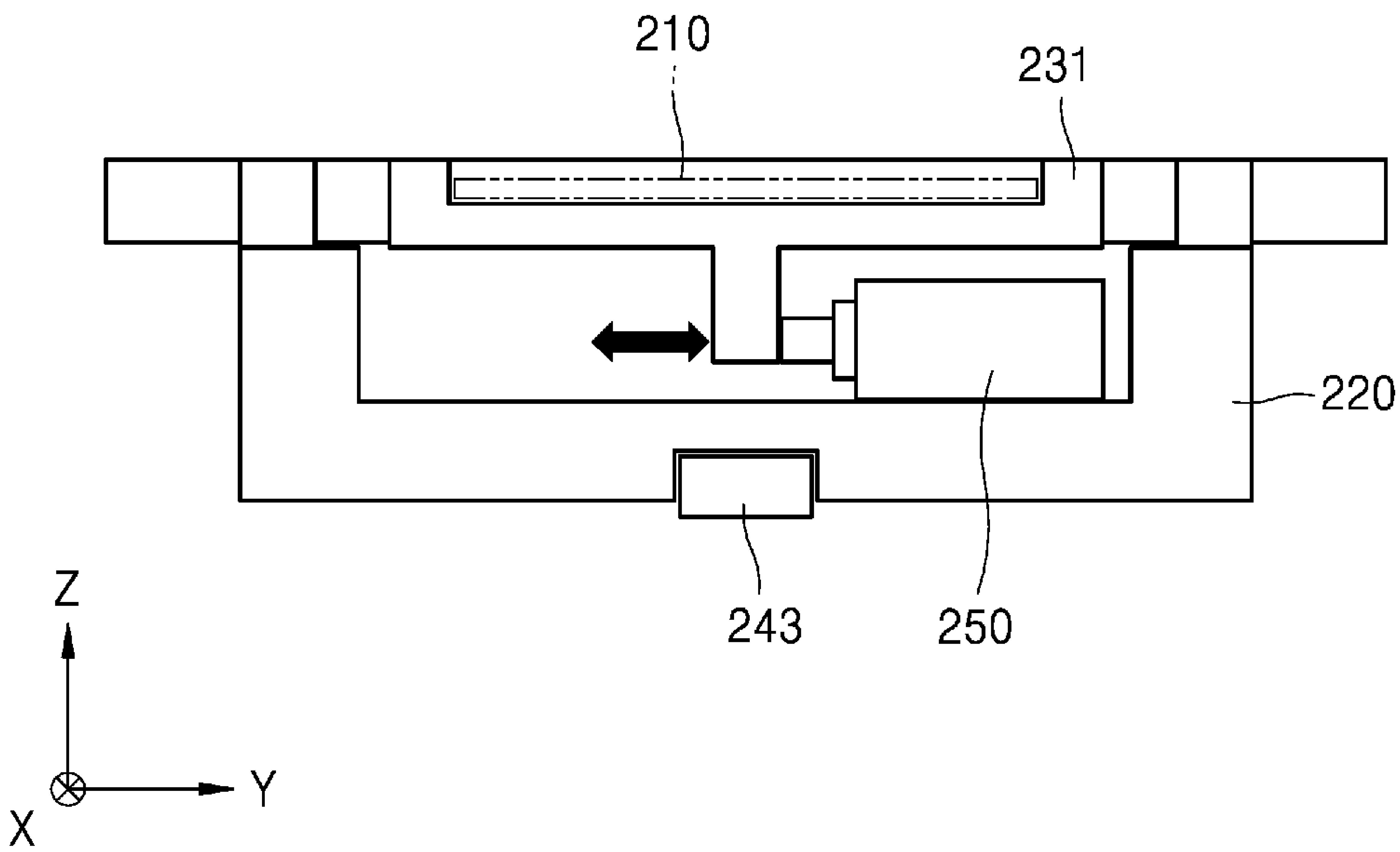
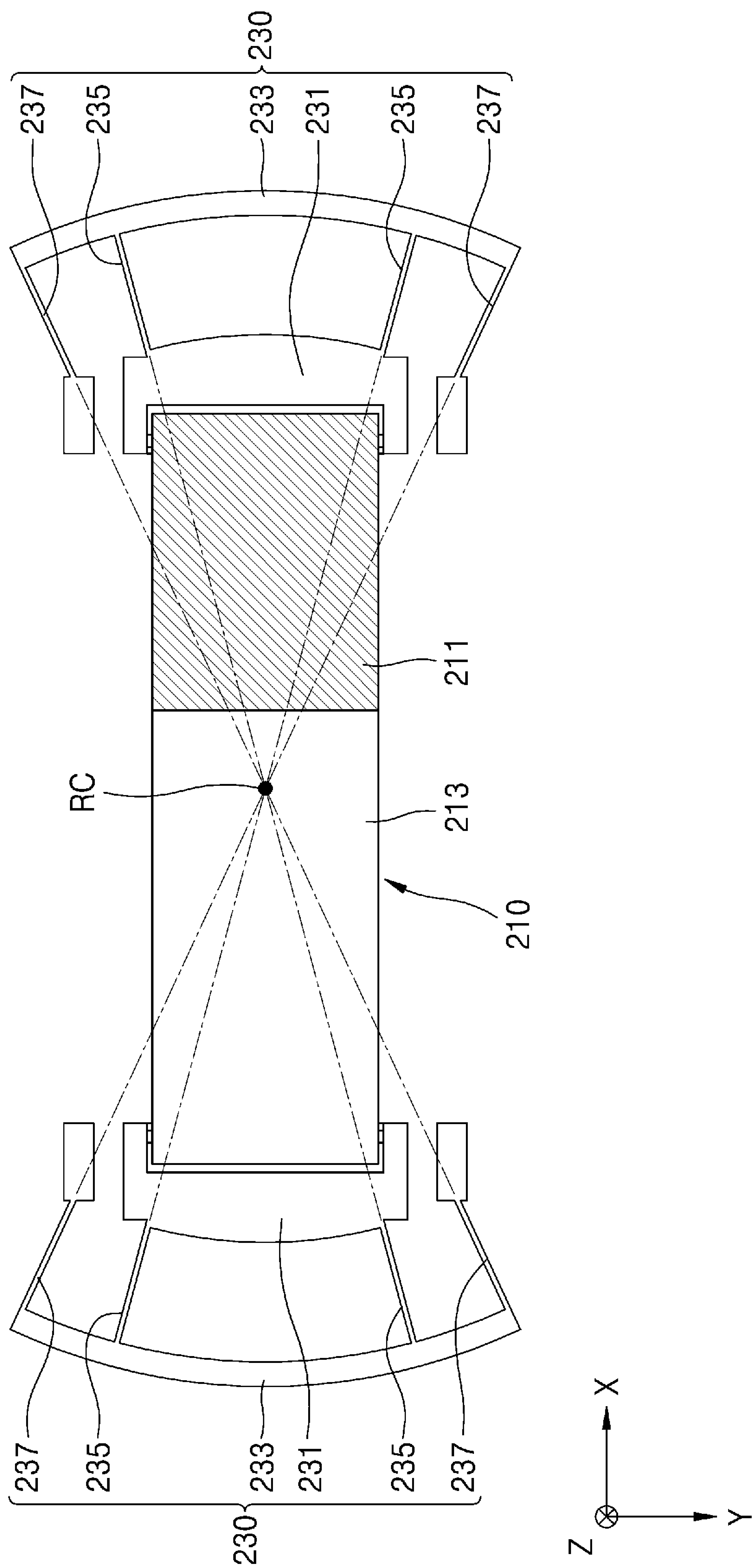


FIG. 16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SEMICONDUCTOR MANUFACTURING APPARATUS INCLUDING A BEAM SHAPER FOR SHAPING A LASER BEAM

CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority under 35 U.S.C. § 119 to Korean Patent Application No. 10-2019-0113524, filed on Sep. 16, 2019, in the Korean Intellectual Property Office, the disclosure of which is incorporated by reference herein in its entirety.

TECHNICAL FIELD

The present inventive concept relates to a semiconductor manufacturing apparatus, and more particularly, to a semiconductor manufacturing apparatus including a beam shaper for shaping a laser beam.

DISCUSSION OF THE RELATED ART

A semiconductor manufacturing apparatus for processing a substrate may include a laser beam for irradiating the substrate. A laser beam output from a light source is shaped by a beam shaper before irradiating the substrate. The beam shaper partially reflects the laser beam by using a reflective mask configured to reflect the laser beam and transmit the laser beam through an opening defined by the reflective mask. Since the beam shaper needs to be tailor designed in accordance with a kind of equipment or a process condition used, it is costly to design an optimized beam shaper whenever new equipment or anew process is applied.

SUMMARY

According to an exemplary embodiment of the present inventive concept, a semiconductor manufacturing apparatus is provided including a beam shaper arranged on a light path of a laser beam and including a plurality of mask modules. The plurality of mask modules defines a light blocking region and a light transmitting region. At least one mask module of the plurality of mask modules includes a blocking plate configured to block a portion of the laser beam. A driver is configured to move the blocking plate.

According to an exemplary embodiment of the present inventive concept, a semiconductor manufacturing apparatus includes a light source configured to emit a laser beam. A beam shaper is arranged on a light path of the laser beam and includes a plurality of mask modules defining a light blocking region and a light transmitting, region. At least one mask module of the plurality of mask modules includes a first blocking plate including a blocking bar defining an edge of the light transmitting region and an opening defined between the blocking bar and the first blocking plate. A second blocking plate is mounted on the first blocking plate to at least partially cover the opening of the first blocking plate. A bar actuator is configured to apply external force to the blocking bar so that the edge of the light transmitting region is concave or convex.

According to an exemplary embodiment of the present inventive concept, a semiconductor manufacturing apparatus is provided including a light source configured to emit a laser beam A beam shaper is arranged on a light path of the laser beam and includes a plurality of mask modules defining a light blocking region and a light transmitting region. Each of the plurality of mask modules includes a mask structure including a transparent substrate and a blocking plate. The blocking plate covers a part of one surface of the transparent substrate. A moving block is movably provided in a linear moving guide. A first stage is configured to support the mask structure and to rotate with respect to a first direction parallel to a direction in which the laser beam proceeds. The first direction is a rotation axis. A second stage spaced apart from the first stage. First flexure blades connect the first stage and the second stage. Second flexure blades connect the second stage and the moving block. A rotary driver is configured to apply external force to the first stage for rotating the first stage.

BRIEF DESCRIPTION OF THE DRAWINGS

Exemplary embodiments of the present inventive concept will be more clearly understood from the following detailed description taken in conjunction with the accompanying drawings in which:

FIG. **1** is a schematic diagram illustrating a side-view of a semiconductor manufacturing apparatus, according to an exemplary embodiment of the present inventive concept;

FIGS. **2**, **3**, **4**A and **4**B are plan-views illustrating methods of operating the beam shaper of FIG. **1**, according to exemplary embodiments of the present inventive concept;

FIGS. **5**A and **5**B are plan views illustrating a beam shaper, according to exemplary embodiments of the present inventive concept;

FIGS. **6**A and **6**B are plan views illustrating a pan of a beam shaper in order to describe a rotary motion of a blocking plate, according to an exemplary embodiment of the present inventive concept;

FIG. **7** is a cross-sectional view illustrating a part of the beam shaper of FIG. **6**A, according to an exemplary embodiment of the present inventive concept;

FIGS. **8**A and **8**B are enlarged plan-views illustrating a method of transforming an edge of a light transmitting region to be concave or convex by transforming a blocking bar of a first blocking plate, according to an exemplary embodiment of the present inventive concept;

FIG. **9** is a perspective view schematically illustrating mask structures included in a beam shaper according, to an exemplary embodiment of the present inventive concept;

FIG. **10** is a cross-sectional view schematically illustrating mask structures included in a beam shaper according to an exemplary embodiment of the present inventive concept;

FIG. **11** is a perspective view illustrating a beam shaper according to an exemplary embodiment of the present inventive concept;

FIG. **12** is a plan view illustrating a first mask module of the beam shaper of FIG. **11**, according to an exemplary embodiment of the present inventive concept;

FIG. **13** is a perspective view illustrating a part of a first mask module of the beam shaper of FIG. **11**, according to an exemplary embodiment of the present inventive concept;

FIG. **14** is a side view illustrating a part of the first mask module seen in a direction of the arrow XIV of FIG. **13**, according to an exemplary embodiment of the present inventive concept;

FIG. **15** is a side view illustrating a part of the first mask module seen in a direction of the arrow XV of FIG. **13**, according to an exemplary embodiment of the present inventive concept; and

FIG. **16** is a plan view illustrating the virtual rotation center of a rotary block of a first mask module, according to an exemplary embodiment of the present inventive concept.

DETAILED DESCRIPTION OF THE EXEMPLARY EMBODIMENTS

Hereinafter, exemplary embodiments of the present inventive concept will be described in detail with reference to the accompanying drawings. Like reference numerals may refer to like elements throughout the specification and the drawings. Redundant description of elements described elsewhere in this application may be omitted for brevity. FIG. **1** is a schematic diagram illustrating a side-view of a semiconductor manufacturing apparatus **10**, according to an exemplary embodiment of the present inventive concept.

Referring to FIG. **1**, the semiconductor manufacturing apparatus **10** may include a light source **31**, a beam shaper **100**, and a stage **35**.

The light source **31** may emit a laser beam LB**1**. The light source **31** may include a laser generator for emitting the laser beam LB**1** having a wavelength of about 400 nm to about 600 nm. In an exemplary embodiment of the present inventive concept, the light source **31** may include a laser generator for emitting an excimer laser beam.

The laser beam LB**1** emitted from the light source **31** is reflected by a reflective mirror **33** positioned in a light path of the laser beam LB**1**. The reflected laser beam LB**1** may be orthogonally reflected with respect to an original trajectory of the laser beam LB**1** owing to an angle of the reflective mirror **33**. The reflected laser beam LB**1** then proceeds through the beam shaper **100** and irradiates substrate S mounted on the stage **35**. The beam shaper **100** is arranged on a light path of the laser beam LB**1** and may shape the laser beam LB**1** prior to irradiating the substrate S. For example, the beam shaper **100** may control a shape and size of a horizontal cross-section of the laser beam LB**1**. Here, the horizontal cross-section of the laser beam LB**1** may mean a cross-section of the laser beam LB**1** on a plane (for example, an X-Y plane) substantially perpendicular to a direction (for example, a Z direction) in which the laser beam LB**1** proceeds.

In an exemplary embodiment of the present inventive concept, the beam shaper **100** may include first to fourth blocking plates **111** formed of a material capable of blocking or reflecting the laser beam LB**1**. The first to fourth blocking plates **111** may define a light blocking region and a light transmitting region (**11** of FIG. **2**) therebetween. The laser beam LB**1** is blocked or reflected by the light blocking region. The remainder of the laser beam LB**1** passes through the central light transmitting region **11** which is at least partially surrounded by the light blocking region. Since the beam shaper **100** selectively transmits the laser beam LB**1** only through the light transmitting region **11**, a horizontal cross-section of a laser beam LB**2** that passes through the beam shaper **100** may be controlled by a shape and size of the light transmitting region **11**.

For example, as illustrated in FIG. **1**, by the first to fourth blocking plates **111** arranged in a circular arrangement with a central gap (e.g., arranged in a clockwise direction), the light transmitting region **11** may be defined to be quadrangular. Here, the shape of the light transmitting region **11** may mean the shape of the light transmitting region **11** seen in the direction in which the laser beam LB**1** proceeds (e.g., in a plan view). The light transmitting region **11** may be rectangular. However, the present inventive concept is not limited thereto. For example, the light transmitting region **11** may be square, parallelogram-shaped, or diamond-shaped.

The first to fourth blocking plates **111** may define the light transmitting region **11** to be, for example, polygonal, for example, triangular, or pentagonal. Alternatively, the first to fourth blocking plates **111** may define the light transmitting region **11** to be circular or elliptical.

Adjacent blocking plates **111** may overlap each other at corners thereof. For example, blocking plates **111** spaced apart in the Y direction may have facing corners disposed superior to respective adjacent corners of the blocking plates **111** spaced apart in the X direction.

The stage **35** may support a material processed by using the laser beam LB**1**. For example, the stage **35** may support the substrate S. In an exemplary embodiment of the present inventive concept, the substrate S may include a semiconductor, such as silicon (Si) and/or germanium (Ge), or a compound semiconductor, such as Silicon-germanium (SiGe), Silicon Carbide (SiC), Gallium Arsenide (GaAs), Indium Arsenide (InAs) and/or Indium Phosphide (InP). In an exemplary embodiment of the present inventive concept, the substrate S may include a conductive region, for example, a well doped with impurities or a structure doped with impurities.

In an exemplary embodiment of the present inventive concept, the stage **35** may be an electrostatic chuck configured to support the loaded substrate S by using electrostatic force. In an exemplary embodiment of the present inventive concept, the stage **35** may be a vacuum chuck configured to support the loaded substrate S by using vacuum pressure. In addition, the stage **35** may include a stage driver for moving and rotating the stage **35**. The stage driver may move and rotate the stage **35** while a material is processed by using the laser beam LB**2** shaped by the beam shaper **100**.

In an exemplary embodiment of the present inventive concept, the semiconductor manufacturing apparatus **10** may be a laser annealing apparatus configured to perform a laser annealing process on the substrate S by using the laser beam LB**1**. For example, the semiconductor manufacturing apparatus **10** may crystallize an amorphous silicon layer of the substrate S into a polysilicon layer by irradiating the substrate S with the laser beam LB**2**. According to an exemplary embodiment of the present inventive concept, the semiconductor manufacturing apparatus **10** may perform a laser doping process of introducing impurities to a semiconductor or a laser deposition process of forming a metal layer and/or an oxide layer by irradiating the substrate S with the laser beam LB**2**.

FIGS. **2**, **3**, **4**A and **4**B are plan-views illustrating methods of operating the beam shaper **100** of FIG. **1**, according to exemplary embodiments of the present inventive concept.

Referring to FIGS. **1** and **2**, the beam shaper **100** may include first to fourth mask modules **101**, **102**, **103**, and **104** arranged in the clockwise direction. Each of the first to fourth mask modules **101**, **102**, **103**, and **104** may include a blocking plate **111** and a driver for moving the blocking plate **111** (e.g., a linear driver **140**).

The linear driver **140** may linearly move the blocking plate **111**. For example, the linear driver **140** may make the blocking plate **111** linearly reciprocate in a first or a second horizontal direction (for example, an X direction and/or a Y direction, respectively) perpendicular to a third direction (for example, the Z direction) in which the laser beam LB**1** proceeds. In an exemplary embodiment of the present inventive concept, the linear driver **140** may include a linear actuator.

In an exemplary embodiment of the present inventive concept, the size and shape of the light transmuting region **11** may be controlled by individually controlling movement (e.g., linear movement) of the first to fourth blocking plates **111**. For example, in order to control a width in a first horizontal direction (for example, the X direction) of the transmitting region **11**, the blocking plate **111** of the first mask module **101** and/or the blocking plate **111** of the third mask module **103** that are spaced apart from each other in the first horizontal direction (e.g., the X direction) may be moved in the first horizontal direction (e.g., the X direction). In addition, in order to control a width in a second horizontal direction (for example, the Y direction) of the transmitting region **11**, the blocking plate **111** of the second mask module **102** and/or the blocking plate **111** of the fourth mask module **104** that are apart from each other in the second horizontal direction (e.g., the Y direction) may be moved in the second horizontal direction (e.g., the Y direction).

Referring to FIGS. **1** and **3**, the beam shaper **100** may include the first to fourth mask modules **101**, **102**, **103**, and **104** arranged in the clockwise direction. Each of the first to fourth mask modules **101**, **102**, **103**, and **104** may include the blocking plate **111** and a rotary driver **150**.

The rotary driver **150** may rotate the blocking plate **111**. For example, the rotary driver **150** may rotate the blocking plate **111** with respect to a third direction (for example, the Z direction) parallel to the direction in which the laser beam LB**1** proceeds as a rotation axis. In an exemplary embodiment of the present inventive concept, the blocking plate **111** may rotate in a fine range of less than 1°, 0.5°, or 0.2° with respect to a rotation axis (e.g., an axis of the Z direction). In an exemplary embodiment of the present inventive concept, the rotary driver **150** may include a piezoelectric actuator capable of precisely controlling a fine rotary motion of the blocking plate **111**.

In an exemplary embodiment of the present inventive concept, by individually controlling the rotation of the first to fourth blocking plates **111**, skewness of the light transmitting region **11** may be controlled. By rotating at least some of the first to fourth blocking plates **111** with respect to the third direction (e.g., the Z direction) as the rotation axis, an angle between adjacent two edges of the light transmitting region **11** may be controlled and the shape of the light transmitting region **11** may be controlled. Skewness of the light transmitting region **11** may refer to a condition in which adjacent sides of the light transmitting region **11** are not orthogonally connected.

In an exemplary embodiment of the present inventive concept, lateral sides of each of the blocking plates **111** may be asymmetrical in a plan view, and thus a shape of the light transmitting region **11** may be changed by rotations of the blocking plates **111** such that a differently shaped side is rotated to face the light transmitting region **11**.

Referring to FIGS. **1**, **4**A and **4**B, the beam shaper **100** may include the first to fourth mask modules **101**, **102**, **103** and **104** arranged in the clockwise direction. Each of the first to fourth mask modules **101**, **102**, **103** and **104** may include the blocking plate **111** and an actuator **160**.

The actuator **160** may apply external force for elastically transforming the blocking plate **111** to the blocking plate **111**. For example, the actuator **160** may elastically transform an edge of the blocking plate **111**, which contacts the light transmitting region **11**, to be concave or convex by applying external force to the blocking plate **111**. In an exemplary embodiment of the present inventive concept, displacement of the center of the edge of the blocking plate **111**, which contacts the light transmitting region **11**, may be less than 100 μm, 50 μm, or 30 μm. In an exemplary embodiment of the present inventive concept, the actuator **160** may include the piezoelectric actuator capable of precisely controlling fine transformation of the blocking plate **111**.

In an exemplary embodiment of the present inventive concept, the beam shaper **100** may correct radial distortion of the laser beam LB**1** by transforming edges of the first to fourth blocking plates **111**. The radial distortion of the laser beam LB**1** may include barrel distortion in which an edge of the laser beam LB**1** is curved outward to be convex and pincushion distortion in which the edge of the laser beam LB**1** is curved inward to be concave. The beam shaper **100** may correct the radial distortion of the laser beam LB**1** by transforming the edges of the first to fourth blocking plates **111** in a direction opposite to a direction in which the edge of the laser beam LB**1** is curved.

In an exemplary embodiment of the present inventive concept, when the barrel distortion occurs in the laser beam LB**1**, as illustrated in FIG. **4**A, the actuator **160** may correct the barrel distortion by transforming an edge of the blocking plate **111** to be convex. For example, the actuator **160** may correct the barrel distortion by transforming the edge of the blocking plate **111** adjacent to the light transmitting region **11** to be convex. In other words, the actuator **160** may correct the barrel distortion by transforming an edge of the light transmitting region **11** to be concave.

In an exemplary embodiment of the present inventive concept, when the pincushion distortion occurs in the laser beam LB**1**, as illustrated in FIG. **4**B, the actuator **160** may correct the pincushion distortion by transforming an edge of the blocking plate **111** to be concave. For example, the actuator **160** may correct the pincushion distortion by transforming the edge of the blocking plate **111** adjacent to the light transmitting region **11** to be concave. In other words, the actuator **160** may correct the pincushion distortion by transforming an edge of the light transmitting region **11** to be convex.

FIGS. **5**A and **5**B are plan views illustrating the beam shaper **100** according to exemplary embodiments of the present inventive concept. FIG. **5**B illustrates the beam shaper **100** from which second blocking plates **115** illustrated in FIG. **5**A are removed.

Referring to FIGS. **5**A and **5**B, the beam shaper **100** may include a plurality of mask modules. The plurality of mask modules may define the light blocking region and the light transmitting region **11** and may control the size and shape of the light transmitting region **11** in cooperation with each other. For example, the beam shaper **100** may include the first to fourth mask modules **101**, **102**, **103**, and **104**. In a plan view, the second to fourth mask modules **102**, **103**, and **104** may be arranged in positions rotated at 90°, 180°, and 270° with respect to the first mask module **101** in the clockwise direction.

Each of the first to fourth mask modules **101**, **102**, **103**, and **104** may include the blocking plate **111**, a moving block **120**, the linear driver **140**, and the rotary driver **150**.

The first to fourth blocking plates **111** included in the first to fourth mask modules **101**, **102**, **103**, and **104** may define the light transmitting region **11** to be quadrangular in cooperation with each other. The light transmitting region **11**, which is quadrangular, may be an opening defined by the first to fourth blocking plates **111**. The first to fourth blocking plates **111** included in two adjacent mask modules among the first to fourth mask modules **101**, **102**, **103**, and **104** may be spaced apart from each other in a vertical direction (e.g., the Z direction). Since the adjacent blocking plates **111** are spaced apart from each other, one blocking plate **111** may move without colliding or interfering with another blocking plate **111**.

In an exemplary embodiment of the present inventive concept, each of the first to fourth blocking plates **111** may include a first blocking plate **113** and a second blocking plate **115** mounted on the first blocking plate **113**. The first blocking plate **113** may include a blocking bar **1135** that defines an edge of the light transmitting region **11** and an opening **1131** that contacts or reaches the blocking bar **1135**. For example, the first blocking plate **113** may have a first side surface disposed between curved second side surfaces which extend oppositely away from the first side surface of the first blocking plate **113**. The blocking bar **1135** may be disposed in parallel to the first side surface of the first blocking plate **113** and between end portions of the curved second side surfaces of the first blocking plate **113**. The opening **1131** may be defined between a surface of the blocking bar **1135** facing the first side surface of the first blocking plate **113** and the first side surface of the first blocking plate **113**. The second blocking plate **115** may be mounted on the first blocking plate **113** to cover the opening **1131** of the first blocking plate **113** and an upper surface of the first blocking plate **113**. The second blocking plate **150** may prevent the laser beam LB**1** from passing through the opening **1131** of the first blocking plate **113**.

The moving block **120** may be disposed on the blocking plate **111**. For example, the moving block **120** may support the blocking plate **111**. The moving block **120** is movably provided in a linear moving guide (**143** of FIG. **7**) and may be guided by the linear moving guide **143** and may linearly move. For example, the blocking plate **111** supported by the moving block **120** may move together with the moving block **120** when the moving block **120** moves.

The linear driver **140** may linearly move the moving block **120** and the blocking plate **111** supported by the moving block **120**. For example, the linear driver **140** may include a linear actuator **141**, the linear moving guide **143** for guiding the linear movement of the moving block **120**, and a linear encoder.

As previously described with reference to FIG. **2**, by individually controlling linear movements of the first to fourth blocking plates **111**, the size of the light transmitting region **11** may be controlled. For example, the linear drivers **140** included in the first and third mask modules **101** and **103** may control a width of the light transmitting region **11** in the first horizontal direction (for example, the X direction) by linearly moving the moving blocks **120** in the first horizontal direction (e.g., the X direction). In addition, the linear drivers **140** included in the second and fourth mask modules **102** and **104** may control a width of the light transmitting region **11** in the second horizontal direction (for example, the Y direction) by linearly moving the moving blocks **120** in the second horizontal direction (e.g., the Y direction).

FIGS. **6**A and **6**B are plan views illustrating a part of a beam shaper in order to describe a rotary motion of a blocking plate, according to an exemplary embodiment of the present inventive concept. FIG. **7** is a cross-sectional view illustrating a part of the beam shaper of FIG. **6**A, according to an exemplary embodiment of the present inventive concept.

Referring to FIGS. **5**A, **5**B, **6**A, **6**B and **7**, each of the first to fourth mask modules **101**, **102**, **103**, and **104** may include a flexure hinge **121** for connecting the blocking plate **111** and the moving block **120** to each other. The flexure hinge **121** may be a swivel joint provided between the blocking plate **111** and the moving block **120**. For example, the flexure hinge **121** may be disposed on a surface of the first blocking plate **113** that is opposite to the light transmitting region **11**. The flexure hinge **121** may extend in the third direction (for example, the Z direction) parallel to the direction in which the laser beam LB**1** proceeds and may allow the blocking plate **111** to rotate about an axis of the third direction (also referred to herein as the rotation axis) and may limit a rotary motion of the blocking plate **111** in another direction (e.g., around an axis of the first horizontal direction or the second horizontal direction).

In an exemplary embodiment of the present inventive concept, the first blocking plate **113**, the moving block **120**, and the flexure hinge **121** may form one body (e.g. integrated or cooperatively coupled).

The rotary driver **150** may rotate the blocking plate **111** by using the third direction (e.g., the Z direction) as the rotation axis. The rotary driver **150** may include an actuator configured to apply external force for rotating the blocking plate **111** to the blocking plate **111**. The actuator of the rotary driver **150** may apply external force to a point of the first blocking plate **113** spaced apart from the flexure hinge **121** in a first horizontal direction (e.g., the X direction) or a second horizontal direction (e.g., the Y direction). For example, the actuator of the rotary driver **150** may be connected to the an end portion of the first blocking plate **113** and may push or pull the contacted end portion of the first blocking plate **113**.

As illustrated in FIG. **6**A, when the rotary driver **150** applies external force to the first blocking plate **113** in a direction A1 in which the rotary driver **150** pushes the first blocking plate **113**, since the external force functions as torque that rotates the first blocking plate **113**, the first blocking plate **113** may rotate based on the flexure hinge **121** on the X-Y plane in a first rotation direction R**1**.

In addition, as illustrated in FIG. **6**B, when the rotary driver **150** applies external force to the first blocking plate **113** in a direction A2 in which the rotary driver **150** pulls the first blocking plate **113**, since the external force functions as torque that rotates the first blocking plate **113**, the first blocking plate **113** may rotate based on the flexure hinge **121** on the X-Y plane in a second rotation direction R**2**.

The rotation of the first blocking plate **113** in the first rotation direction R**1** and the rotation of the first blocking plate **113** in the second rotation direction R**2** may be minutely implemented by the elastic transformation of the flexure hinge **121**. In an exemplary embodiment of the present inventive concept, a rotation angle θ**1** of the first blocking plate **113** in the first rotation direction R**1** and a rotation angle θ**2** of the first blocking plate **113** in the second rotation direction R**2** may be implemented in a fine range of less than 1°, 0.5°, or 0.2° with respect to a rotation axis (e.g., an axis of the Z direction). For example, the rotation angles θ**1** and θ**2** may represent angles of deviation of a surface of the first blocking plate **113** towards or away from the moving block **120** from a resting position.

In an exemplary embodiment of the present inventive concept, the actuator of the rotary driver **150** may include a piezoelectric actuator capable of precisely controlling the rotation of the blocking plate **111**. However, the present inventive concept is not limited thereto.

As described with reference to FIG. **3**, the rotary drivers **150** may control a skewness of the light transmitting region **11** by individually controlling the rotations of the first to fourth blocking plates **111**. For example, by rotating at least one of two adjacent blocking plates **111**, the shape of the light transmitting region **11** or an angle between two adjacent edges of the light transmitting region **11** may be controlled.

FIGS. **8**A and **8**B are enlarged plan-views illustrating a method of transforming an edge of the light transmitting region **11** to be concave or convex by transforming the blocking bar **1135** of the first blocking plate **113**.

Referring to FIGS. **8**A and **8**B together with FIG. **5**B, each of the first to fourth mask modules **101**, **102**, **103**, and **104** may include the bar actuator **160** so as to transform the blocking bar **1135**. The bar actuator **160** may apply external force to the blocking bar **1135** so that the blocking bar **1135** is elastically transformed. For example, the bar actuator **160** may be connected to the center of the blocking bar **1135** and may push or pull the center of the blocking bar **1135**. The elastic transformation of the blocking bar **1135** is implemented in a fine range. For example, displacement of the center of the blocking bar **1135** in the first horizontal direction (e.g., the X direction) or the second horizontal direction (e.g., the Y direction) may be less than 100 μm, 50 μm, or 30 μm.

According to an exemplary embodiment of the present inventive concept, the actuator **160** may retract or extend in a horizontal direction to provide the pulling or pushing force, respectively.

In an exemplary embodiment of the present inventive concept, the bar actuator **160** may include a piezoelectric actuator capable of precisely controlling the elastic transformation of the blocking bar **1135**. However, the present inventive concept is not limited thereto.

As previously described with reference to FIGS. **4**A and **4**B, the bar actuators **160** included in the first to fourth mask modules **101**, **102**, **103**, and **104** may correct the barrel distortion or pincushion distortion of the laser beam LB**1** by controlling directions in which the centers of the blocking bars **1135** are curved.

In an exemplary embodiment of the present inventive concept, when the barrel distortion occurs in the laser beam LB**1**, the bar actuator **160** may correct the barrel distortion by transforming the blocking bar **1135** so that an edge of the blocking bar **1135** is curved toward the center of the light transmitting region **11**.

In an exemplary embodiment of the present inventive concept, when the pincushion distortion occurs in the laser beam LB**1**, the bar actuator **160** may correct the pincushion distortion by transforming the blocking bar **1135** so that an edge of the blocking bar **1135** is curved to be away from the center of the light transmitting region **11**.

FIG. **9** is a perspective view schematically illustrating a plurality of mask structures **210** included in a beam shaper **200**, according to an exemplary embodiment of the present inventive concept. FIG. **10** is a cross-sectional view schematically illustrating a plurality of mask structures **210** included in a beam shaper **200**, according to an exemplary embodiment of the present inventive concept.

Referring to FIGS. **9** and **10**, the beam shaper **200** may include the plurality of mask structures **210** that define a light blocking region and a light transmitting region **21** in cooperation with each other. For example, each of the plurality of mask structures **210** may shape the laser beam LB**1** incident on the beam shaper **200** by selectively transmitting the laser beam LB**1**.

The light transmitting region **21** may be defined by blocking plates **211** included in the plurality of mask structures **210**. For example, when the beam shaper **200** includes a plurality of mask structures **210**, in a plan view, around the uppermost mask structure **210**, the remaining three mask structures **210** may be arranged in positions rotated at 90°, 180°, and 270° in the clockwise direction. In this case, the four blocking plates **211** included in the plurality of mask structures **210** may define the light transmitting region **21** to be quadrangular. Each blocking plate **211** may define a respective edge of the light transmitting region **21**.

The plurality of mask structures **210** may be arranged so that normal surfaces thereof are perpendicular to the direction in which the laser beam LB**1** proceeds and may be spaced apart from each other in a vertical direction (e.g., the Z direction), For example, when a thickness of the mask structure **210** in the vertical direction (e.g., the Z direction) is 300 μm to 500 μm, a distance **23** between mask structures **210** adjacent to each other in the vertical direction may be 100 μm to 200 μm.

Each of the plurality of mask structures **210** may include a transparent substrate **215**, a blocking plate **211** that at least partially covers a first part of a surface of the transparent substrate **215**, and a transmitting plate **213** that at least partially covers a second part of the surface of the transparent substrate **215**.

The plurality of mask structures **210** may be arranged so that surfaces on which the blocking plates **211** are provided face upward or downward. For example, as illustrated **10**, when the plurality of mask structures **210** are sequentially arranged in the direction in which the laser beam LB**1** proceeds (e.g., from top to bottom) the blocking plates **211** and the transmitting plates **213** may be arranged on lower surfaces of the transparent substrates **215** in the first and third mask structures and, in the second and fourth mask structures the blocking plates **211** and the transmitting plates **213** may be arranged on upper surfaces of the transparent substrates **215**.

The transparent substrates **215** may include a material having high transmittance with respect to the laser beam LB**1**. In an exemplary embodiment of the present inventive concept, the transparent substrates **215** may be formed of fused silica glass.

The blocking plates **211** may include a material having high reflectivity with respect to the laser beam LB**1**. In an exemplary embodiment of the present inventive concept, the blocking plates **211** may be high reflection (HR) coating layers deposited on the transparent substrates **215**.

The transmitting plates **213** may increase transmittance with respect to the laser beam LB**1**. In an exemplary embodiment of the present inventive concept, the transmitting plates **213** may be anti-reflection (AR) coating layers deposited on the transparent substrates **215**.

In an exemplary embodiment of the present inventive concept, the beam shaper **200** may include a driving device capable of linearly moving or rotating the plurality of mask structures **210**. The beam shaper **200** may control a size of the light transmitting region **21** by linearly moving the plurality of mask structures **210** or may control a shape of the light transmitting region **21** by rotating the plurality of mask structures **210** about the rotation axis of the third direction (e.g., the Z direction) parallel to the direction in which the laser beam LB**1** proceeds.

FIG. **11** is a perspective view illustrating the beam shaper **200** according to an exemplary embodiment of the present inventive concept. FIG. **12** is a plan view illustrating first mask module **201** of the beam shaper **200** of FIG. **11**. FIG. **13** is a perspective view illustrating a part of the first mask module **201** of the beam shaper **200** of FIG. **11**. FIG. **14** is a side view illustrating a part of the first mask module **201** seen in a direction of the arrow XIV of FIG. **13**. FIG. **15** is a side view illustrating a part of the first mask module **201** seen in a direction of the arrow XV of FIG. **13**. In FIGS. **12** to **15**, the first mask module **201** of FIG. **11** is illustrated as being flipped.

Referring to FIGS. **11**, **12**, **13**, **14** and **15**, the beam shaper **200** may include a plurality of mask modules. The plurality of mask modules may define a light blocking region and a light transmitting region **21** in cooperation with each other and may control a size and shape of the light transmitting region **21** in cooperation with each other.

For example, the beam shaper **200** may include the first to fourth mask modules **201**, **202**, **203**, and **204** spaced apart from each other in a vertical direction (e.g., the Z direction). In a plan view, the second to fourth mask modules **202**, **203**, and **204** may be arranged in positions rotated at 90°, 180°, and 270° in the clockwise direction with respect to the first mask module **201** arranged at the uppermost portion.

Each of the first to fourth mask modules **201**, **202**, **203**, and **204** may include the first to fourth mask structure **210**. As described above with reference to FIGS. **9** and **10**, the plurality of mask structures **210** may be stacked in a vertical direction (e.g., the Z direction) and the plurality of mask structures **210** included in the second to fourth mask modules **202**, **203**, and **204** may be arranged in positions rotated at 90°, 180°, and 270° with respect to the first mask structure **210** included in the first mask module **201**.

Each of the first to fourth mask modules **201**, **202**, **203**, and **204** may include a moving block **220**, a rotary block **230**, a linear driver **240**, and a rotary driver **250**.

The moving block **220** may be movably provided in a linear moving guide **243**. For example, the moving block **220** may be guided by the linear moving guide **243** and may linearly reciprocate in the first horizontal direction (for example, the X direction) or the second horizontal direction (for example, the Y direction).

The rotary block **230** may support the mask structure **210**, The rotary block **230** may be provided on the moving block **220** and may linearly move together with the moving block **220**. In addition, the rotary block **230** may be provided on the moving block **220** so as to rotate with respect to the third direction (for example, the Z direction) parallel to the third direction in which the laser beam LB**1** proceeds in a state in which the rotary block **230** supports the mask structure **210**. For example, the rotary block **230** may have a rotary flexure structure in which at least a part of the rotary block **230** is elastically transformed by external force so that the rotary block **230** may perform a rotary motion with respect to the first direction (e.g., the X direction).

One mask module may include a pair of moving blocks **220** and a pair of rotary blocks **230**. A first moving block **220** may be connected to a first rotary block **230** that supports a first end of the mask structure **210**, and a second moving block **220** may be connected to a second rotary block **230** that supports a second end of the mask structure **210**.

The linear driver **240** may linearly move the moving block **220**. The linear driver **240** may control linear movement of the rotary block **230** and linear movement of the mask structure **210** supported by the rotary block **230** by controlling linear movement of the moving block **220**. For example, the linear driver **240** may include a linear actuator **241**, the linear moving guide **243** for guiding the linear movement of the moving block **220**, and a linear encoder.

In an exemplary embodiment of the present inventive concept, linear movements of the pair of moving blocks **220** may be controlled by different linear drivers **240**. At this time, the linear drivers **240** are controlled in parallel by a master-slave method and may prevent unintended pressure or tension from being applied to the mask structure **210**.

The rotary driver **250** may rotate the rotary block **230** by using the third direction (e.g., the Z direction) as the rotation axis. The rotary driver **250** may include an actuator configured to apply external force for rotating the rotary block **230** to the rotary block **230**. In an exemplary embodiment of the present inventive concept, the actuator of the rotary driver **250** may include a piezoelectric actuator. However, the present inventive concept is not limited thereto.

FIG. **16** is a plan view illustrating the virtual rotation center RC of the rotary block **230** of the first mask module **201**.

Referring to FIG. **16** together with FIGS. **13**, **14** and **15**, the rotary block **230** may include a first stage **231** configured to support the mask structure **210** and to rotate with respect to the third direction (e.g., the Z direction), or the rotation axis. A second stage **233**, which is arc-shaped, is spaced apart from the first stage **231**. First flexure blades **235** connect the first stage **231** and the second stage **233** to each other, and second flexure blades **237** connect the second stage **233** and the moving block **220** to each other.

The first flexure, blade **235** may be a sheet-shaped member in which a width in a vertical direction (e.g., the Z direction) is greater than a width in a first horizontal direction (e.g., the X direction) or second horizontal direction (e.g., the Y direction). When external force is applied to the first flexure blade **235**, the first flexure blade **235** may be easily transformed or bent in the first horizontal direction (e.g., the X direction) and the second horizontal direction (e.g., the Y direction) and might not be transformed or bent in the vertical direction (e.g., the Z direction). Therefore, the first flexure blades **235** may allow movement of the first stage **231** in the first horizontal direction (e.g., the X direction) or the second horizontal direction (e.g., the Y direction) and may limit movement of the first stage **231** in the vertical direction (e.g., the Z direction).

The second flexure blades **237** may be spaced apart from each other with the first flexure blades **235** therebetween. Like the first flexure blades **235**, the second flexure blade **237** may be a sheet-shaped member in which a width in a vertical direction (e.g., the Z direction) is greater than a width in a horizontal direction (e.g., the Y direction). When external fierce is transmitted to the second flexure blade **237**, the second flexure blade **237** may be easily transformed or bent in the first horizontal direction (e.g., the X direction) or the second horizontal direction (e.g., the Y direction) and might not be transformed or bent in the vertical direction (e.g., the Z direction).

The actuator of the rotary driver **250** may apply external force for rotating the first stage **231** to the first stage **231**. For example, as illustrated in FIG. **15**, the actuator of the rotary driver **250** may be connected to a first portion of the first stage **231** and may push or pull the first portion of the first stage **231** in one direction (for example, the Y direction).

When external force is applied by the actuator to the first stage **231**, the first flexure blades **235** connected to the first stage **231** are elastically transformed and the first stage **231** and the mask structure **210** supported by the first stage **231** may rotate. The first stage **231** and the mask structure **210** supported by the first stage **231** may rotate around the virtual rotation center RC. The virtual rotation center RC may be an intersection point of extensions to the two second flexure blades **237**.

In exemplary embodiments of the present inventive concept, rotations of the pair of rotary blocks **230** may be controlled by different rotary drivers **250**, The rotary drivers **250** may be controlled in parallel by a master-slave method and may prevent unintended pressure or tension from being applied to the mask structure **210**.

In general, since a mask for shaping a laser beam needs to be changed in accordance with a specific kind of equipment or a process condition, in order to design a mask suitable for new equipment or a new process condition, remarkable cost occurs. However, according to exemplary embodiments of the present inventive concept, since a mask optimized to a kind of equipment or a process condition may be rapidly changed while freely controlling a size and shape of a light transmitting region defined by a plurality of light blocking plates, the cost required for manufacturing a mask may be remarkably reduced and productivity of semiconductor manufacturing may increase.

While exemplary embodiments of the present inventive concept have been particularly shown and described heretofore, it will be understood that various changes in form and details may be made therein without departing from the spirit and scope of the present inventive concept.

What is claimed is:

1. A semiconductor manufacturing apparatus, comprising:

a beam shaper arranged on a light path of a laser beam and including a plurality of mask modules, the plurality of mask modules defining a light blocking region and a light transmitting region, wherein at least one mask module of the plurality of mask modules comprises:

a blocking plate configured to block a portion of the laser beam;

a driver configured to move the blocking plate;

a moving block movably provided in a linear moving guide; and

a flexure hinge connecting the moving block and the blocking plate.

2. The semiconductor manufacturing apparatus of claim **1**, wherein the light transmitting region is an opening defined by blocking plates included in the plural of mask modules.

3. The semiconductor manufacturing apparatus of claim **1**, wherein at least one mask module of the plurality of mask modules farther comprises a rotary driver configured to rotate the blocking plate with respect to a first direction, wherein the first direction is a rotation axis of the blocking plate.

4. The semiconductor manufacturing apparatus of claim **3**, wherein the rotary driver controls skewness of the light transmitting region by rotating the blocking plate with respect to the first direction which is the rotation axis.

5. The semiconductor manufacturing apparatus of claim **1**, wherein the blocking plate, the moving block, and the flexure hinge form one body.

6. The semiconductor manufacturing apparatus of claim **1**, wherein the blocking plate comprises:

a first blocking plate including a blocking bar defining an edge of the light transmitting region and an opening defined between the blocking bar and the first blocking plate; and

a second blocking plate at least partially covering the opening of the first blocking plate.

7. The semiconductor manufacturing apparatus of claim **6**, wherein at least one mask module of the plurality of mask modules comprises a bar actuator configured to apply external force to the blocking bar so that the one edge of the light transmitting region defined by the blocking bar is concave or convex.

8. The semiconductor manufacturing apparatus of claim **1**, further comprising a stage on which a substrate is mounted, wherein the semiconductor manufacturing apparatus performs a laser annealing process on the substrate by using the laser beam shaped by the beam shaper.

9. A semiconductor manufacturing apparatus, comprising:

a light source configured to emit a laser beam; and

a beam shaper arranged on a light path of the laser beam and including a plurality of mask modules defining a light blocking region and a light transmitting region,

wherein at least one mask module of the plurality of mask modules comprises:

a first blocking plate including a blocking bar defining an edge of the light transmitting region and an opening defined between the blocking bar and the first blocking plate;

a second blocking plate mounted on the first blocking plate to at least partially cover the opening of the first blocking plate; and

a bar actuator configured to apply external force to the blocking bar so that the edge of the light transmitting region is concave or convex.

10. The semiconductor manufacturing apparatus of claim **9**, wherein at least one mask module of the plurality of mask modules comprises:

a moving block movably provided in a linear moving guide; and

a flexure hinge connecting the moving block and the first blocking plate, and

wherein the first blocking plate, the moving block, and the flexure hinge form one body.

11. The semiconductor manufacturing apparatus of claim **10**, further comprising a rotary driver configured to apply external force for rotating the first blocking plate to the first blocking plate with respect to a first direction parallel to a direction in which the laser beam proceeds, wherein the first direction is a rotation axis, wherein the first blocking plate is rotated at the flexure hinge by the external force applied from the rotary driver.

12. The semiconductor manufacturing apparatus of claim **10**, wherein at least one mask module of the plurality of mask modules thither comprises a linear actuator configured to linearly move the moving block.

13. The semiconductor manufacturing apparatus of claim **9**, wherein the bar actuator comprises a piezoelectric actuator.

14. A semiconductor manufacturing apparatus, comprising:

a light source configured to emit a laser beam; and

a beam shaper arranged on a light path of the laser beam and including a plurality of mask modules defining a light blocking region and a light transmitting region,

wherein each of the plurality of mask modules comprises:

a mask structure including a transparent substrate and a blocking plate, the blocking plate covering a first part of one surface of the transparent substrate;

a moving block movably provided in a linear moving guide;

a first stage configured to support the mask structure and to rotate with respect to a first direction parallel to a direction in which the laser beam proceeds, the first direction is a rotation axis;

a second stage spaced apart from the first stage;

first flexure blades connecting the first stage and the second stage;

second flexure blades connecting the second stage and the moving block; and

a rotary driver configured to apply external force to the first stage for rotating the first stage.

15. The semiconductor manufacturing apparatus of claim **14**, wherein the mask structure further comprises a transmitting plate covering a second part of the surface of the transparent substrate.

16. The semiconductor manufacturing apparatus of claim **15**, wherein the blocking plate includes a high reflection (HR) coating layer, and wherein the transmitting plate includes an anti-reflection coating layer.

17. The semiconductor manufacturing apparatus of claim **14**, wherein each of the plurality of mask modules further comprises a linear actuator configured to linearly move the moving block.

18. The semiconductor manufacturing apparatus of claim **14**, wherein when the mask structure is provided in plural, each of the plurality of mask modules are spaced apart from each other in a vertical direction.

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